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IMPROVED AND COST EFFECTIVE MACHINING TECHNIQUES

FOR TRACKED COMBAT VEHICLE PARTS

CONTRACT NUMBER DAAK30-79-C-0101

OCTOBER 1983

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The project purpose was to develop improved and cost effective machining data for Tracked Combat Vehicle Materials. The contractor analyzed current machining practices; tested and evaluated tool type/design, cutting fluids and machining conditions; and developed a machining handbook. The contractor solved some specific problems related to tooling.

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SUMMARY

This report covers work performed by Metcut Research Associates Inc. during a 48 month program designed to reduce the acquisition costs of tracked combat vehicles by lowering metal removal costs. The program consisted of three consecutive phases, each similar in format and purpose, contingent on the government's desire to continue the program through the next time period. Each phase consisted of the same five tasks:

TASK 1 - Plan machining tests based on analyzing current practices and problems at prime and subcontractor's manufacturing facilities.

TASK 2 - Conduct machining tests, using statistical modeling techniques. Specific machining operations were performed on relevant alloys based on the analysis of TASK 1.

TASK 3 - Using the machining data developed during TASK 2, conduct machining economic analyses to demonstrate cost-effective machining conditions.

TASK 4 - Hold technical briefings to demonstrate the use of the technical handbook produced at the end of the program.

TASK 5 - Report the progress of the program through quarterly reports and a final technical report.

Interviewing various manufacturing personnel at the Avco engine plant and the Lima tank plant revealed a number of machining problems at these facilities. These machining problems generally fell into two major categories:

- low metal-removal rates and/or unacceptable tool life.
- inability to easily evaluate new developments in tooling, cutting fluids, etc. for state-of-the-art machining practices.

Since machining productivity and on-time delivery of tank parts were often affected by these problems, a significant amount of the contract effort was expended toward improvements in these two areas. On-site technical assistance by Metcut personnel was initiated by the TACOM project manager early in the program. As this effort began to show immediate payback, its continuation was naturally encouraged. The primary area of concentration for this assistance was the application of tooling. The cutting tool industry was very dynamic during this four-year period. The implementation of some of the newer tooling developments resulted in excellent improvements in tool life and metal-removal rates.

Purchasing cutting tools on the basis of competitive price is a risky practice. The quality of high speed steel cutting tools can, and does, vary considerably with the manufacturer. Poor quality tools cause low and erratic tool life on the machining floor, resulting in excessive machine tool downtime. Tests were performed to compare the relative performance of several manufacturers' drills and taps. Most high speed steel cutting tools are designed for multiple regrinds to extend the usable life. A reground tool must have the correct tool geometry reproduced on it to perform satisfactorily. In addition, the grinding parameters must reproduce the geometry without causing surface integrity damage. This metallurgical alteration (damage) reduces a tool with a good geometry to a poor quality tool, by lowering (usually) the hardness of the high speed steel. The softer-than-normal high speed steel produces lower-than-normal tool life and more machine tool downtime. A great deal of attention was focused on helping to solve regrinding problems on high speed steel drills and milling cutters.

In addition to this and other assistance rendered directly to the prime and subcontractors, several ferrous and non-ferrous alloys were subjected to wide-range machining and grinding tests. These test data are the pertinent information along with the basic machining parameters contained in the Machining Handbook produced as partial fulfillment of this contract.

PREFACE

This report covers work performed during 48 months on a program sponsored by the U. S. Army Tank Automotive Command, Warren, MI, under Contract DAAK30-79-C-0101. The TACOM Project Manager was Ms. Jan Dentel, and the Metcut Research Program Manager was John D. Christopher.

The contributors to this report are W. Koster, G. Wuebbling, W. Zdeblick, J. Lindberg, C. Sheffield and H. Hatter - Metcut Research.

The program manager and other participants acknowledge valuable discussions with R. Martire, N. Miller and J. Petrino - Avco Lycoming Division; M. Stein and M. Snyder - General Dynamics Land Systems Division at Lima, OH. In addition to providing useful technical input, the persons mentioned above also provided scrap parts of various alloys as workpiece materials for the machining tests. Without this timely assistance, this program would have been severely limited. Additional technical input was provided early in the program by J. Brusnigham - FMC, San Jose, CA.

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1.0 INTRODUCTION

The purpose of this program was to develop improved and cost-effective combinations of cutting tools, cutting fluids, and machining conditions such as speed, feed, and depth of cut for each of the important machining operations on specific ferrous and nonferrous alloys used for major tracked combat vehicle parts.

The program was accomplished in three phases. To provide the Government with program flexibility, the second and third phases were considered as options, and were subsequently initiated by the Government's unilateral action. The total time span of the contract was 48 months, from September 1979 to August 1983.

2.0 OBJECTIVES

The program objectives were:

- To perform analysis of current and planned machining methods for the manufacture of tracked combat vehicle components, to identify these methods for their applicability to optimization and cost effectiveness testing.

- To perform testing and evaluation of cutting tool type and design, cutting fluids, and machining conditions to maximize the efficiency and cost effectiveness of these machining methods.

- To summarize the results of the study in a series of data tables listing recommended cutting tool, geometry, speed, feed, depth of cut, and cutting fluid for each of the work material and machine operation combinations tested.

3.0 CONCLUSIONS

The most severe machining problems occurred on predictable work materials:

- o Nickel or cobalt high temperature alloys used in gas turbine tank engine.
- o High hardness steels used for various armor sections.
- o Welded and/or flame cut areas of armor steel.
- o Cast armor steel.

The size of some of the M1 tank components created rigidity problems when spindles were required to reach long distances to perform machining operations.

Tapping acceptable quality, internal threads was a continuing problem in many tank-related alloys.

Many of the new developments in cutting tools such as coated carbides, coated high speed steels, and high strength silicon nitride ceramics were compatible with tank component alloys. These tools usually provided longer tool life and/or a higher metal removal rate.

4.0 RECOMMENDATIONS

4.1 Implementation - It is suggested that the TACOM Project Manager exercise diligence to see that the various copies of the handbook of machining data be disseminated as thoroughly as possible. Care should be taken to deliver the handbook to strategic manufacturing personnel as well as to the contractor's technical librarian.

4.2 Continuation - This program has addressed and solved several machining problems that were decreasing productivity and delaying delivery on tank parts. However, recent face-to-face as well as telephone contact with manufacturing personnel has revealed that new manufacturing problems continue to be identified as "bottlenecks" to normal productivity. The contractors and subcontractors still do not have a convenient method or place to evaluate cutting tools and cutting fluids. As new alloys (such as high hardness armor) are introduced, new machining problems emerge. To insure maximum productivity at the lowest possible cost, state-of-the-art manufacturing techniques must be utilized. This is not possible without a cost-effective evaluation. The service which Metcut Research has performed for the Army during this contract has proved to be very useful for reducing contractor and subcontractor manufacturing costs. Access to an off-line testing facility to evaluate new tooling and cutting fluids saves valuable time and avoids manufacturing interruptions. The expertise and flexibility of equipment in the laboratory can usually lead to a much quicker solution to machining problems that so profoundly affect productivity.

A renewal of this type of program will continue to produce cost savings in Army manufacturing contracts and help to insure against delays in on-time deliveries of tanks and tank parts.

5.0 DISCUSSION OF CONTRACT ACTIVITY

The objectives of this contract were twofold. The first objective was to analyze the current and the planned machining methods for manufacturing tracked combat vehicle components with emphasis on the Ml Abrams tank and to identify these methods for their applicability to optimization and cost-effectiveness testing. The second objective was to test and evaluate cutting tools, cutting fluids and machining conditions to maximize cost efficiency and cost effectiveness on the specific alloys that were being used in tracked combat vehicles.

The first objective was not accomplished due to the lack of cooperation from the manufacturing personnel employed by the Chrysler Corporation at the beginning of this contract. Several meetings with the manufacturing people at the Chrysler Tank Plant in Warren, MI revealed their total lack of interest in this program and their complete unwillingness to cooperate with the objectives of this program. The contract that the Chrysler Corporation had with the U. S. Army had a two-year hands-off provision whereby the Army could not interfere with the manufacturing procedures at the Chrysler plant until the end of that period. This contract began during that two-year period. Consequently, the U. S. Army was unable to exert any influence on the Chrysler Corporation to convince them they should cooperate with this program. The Chrysler people felt the machining parameters that were currently being used to manufacture M60 tanks were proprietary information and, therefore, could not be shared to fulfill the objectives of this program.

Since the Ml tank was in its start-up mode, there was little or no historical manufacturing data available there. The armor plate itself was a new alloy and not the same as the cast materials used on the M60 tank. Lacking the ability to identify current tank manufacturing parameters and incorporate these data into the scope of this program, it was essentially impossible to fulfill the program's first objective.

The second objective, to test cutting tools and cutting fluids, and develop machining parameters for the alloys used in the Ml tank, was reasonably achieved. After the two-year time period had expired, the Army used its influence to at least convince the Chrysler Corporation that they could release scrap materials to Metcut to use as work material in fulfilling the second objective of this program. Without cooperation in this area, the program would have been severely hampered. It would have been difficult, if not impossible, to develop realistic data without using the actual armor pieces and other actual alloys involved in legitimate tank parts.

The FMC Corporation located in San Jose, California was the other major manufacturer involved in this program. FMC manufactures the M2 and M3 Bradley Fighting Vehicles, also for the Army. Since both of these vehicles are tracked combat vehicles, they were included within the scope of this program. When the people at Chrysler Warren Tank Plant voiced their unwillingness to be involved with this program, the program manager at TACOM suggested that we contact the FMC Corporation for their input and involvement. A visit was then made in January 1980 to the plant in San Jose. The people there were extremely cooperative and very interested in this program. A review of their machining situation revealed very little machining bottlenecks or particular machining problems. They did identify a series of alloy steels at a hardness range of approximately 40 HRC where they experienced occasional difficulty. A single alloy, 4140 steel, heat treated to the proper hardness level, was chosen as the representative work material to develop machining data relative to the M2 and M3 tracked vehicles.

A meeting was held with the TACOM personnel and the military personnel from the M1 office to discuss the course of this contract after the Chrysler disinterest had been shown. The Army Major from the M1 office instructed that we develop our own machining recommendations database. The Army would then have the data available for costing any future vehicles using this particular family of alloys. The course of the program was then modified to emphasize the development of machining data, realizing that review of the previous or existing machining practices was a difficult course. Work materials in the form of scrap pieces were eventually obtained from both the Chrysler plants in Lima, Ohio, and Warren, Michigan, to use for machinability tests. In addition to these, other work materials were later obtained from the Avco-Lycoming Division located in Stratford, Connecticut. Other strategic materials (castings) were purchased from various vendors in order to provide work material for developing machining data.

In May of 1980, the TACOM office was contacted by an official of the Avco-Lycoming Division in Stratford, Connecticut, requesting funds to support testing for solving machining problems at that location. Since this contract was already in effect, the program manager contacted Metcut and instructed us to see if we could help Avco with their machining problems. The initial visit to Avco was made shortly thereafter, and additional visits continued through November 1982. A total of 13 trips were made to this facility to assist them in solving their machining problems. This need was related to their unique series of high temperature alloys used in the gas turbine engine for the M1 tank.

A new flexible machining line had been recently installed at the Avco plant. The manufacturing people were experiencing a great deal of downtime on the flexible machining line. There were 10 machine tools involved in this system. It was seldom that more than three or four machines at any one time would be in operation. It was quite common for a machine to be down several days as a result of a wreck between the spindle and the workpiece or the workpiece fixture.

Most of the early problems with the flexible line were traceable to the lack of tooling support for that line. When the line was started up, there were insufficient tools and tool holders to support its production capability. To compensate for the shortage of properly ground correct tools, the operators tried to skip machining sequences in order to utilize the available tools and wait for unavailable tools. This practice caused considerable machine tool problems. Some of the lesser-skilled operators were unable to successfully skip sequences without crashing the machine spindle into the workpiece. This was not an everyday occurrence, but it happened often enough to cause a great deal of downtime on the machines. Since there was redundancy in the line (that is, duplication of machines), the line would not be shut down when one machine would be out of service. However, the overall efficiency and productivity of the line was not realized until the tooling problems were solved. Through some careful accounting of tool inventory and diligence on the part of the tool crib manager, these problems were finally resolved and the flexible machining line was able to perform much of the work for which it had been designed and installed.

Because of the natural difficulty of machining high temperature alloys (those materials that generally contain high percentages of nickel and/or cobalt), machining problems were always present. Even some common materials such as cast stainless steel caused problems in certain operations, such as tapping.

Occasionally, inferior tools would be purchased through the practice of buying on lowest bid. Poor quality cutting tools caused significant downtime. Tests were performed on samples of drills and taps from each potential supplier. These test results revealed the relative performance of each supplier's product.

Several new developments in cutting tools were examined for their suitability on the work materials used not only on the flexible machining line, but also in other machining areas that were making parts for the gas turbine engine in the M1 tanks. Some of these cutting tools such as coated carbides, coated high-speed steel drills and coated taps, proved to be highly successful in many applications on the gas turbine work materials.

Another area of concern that surfaced during the various trips to Avco involved the procedures followed in the cutter grinding department. Some of the grinding procedures were not good practices. Poorly reground tools were causing problems when used on the machine tools. A poorly reground tool is no different from a poorly manufactured tool. Both result in a lack of accuracy in the cut, or poor tool life. Both of these problems had occurred, but ultimately were solved with the addition of better regrinding equipment and the modification of certain grinding procedures. As key supervisory personnel became more educated concerning the nature of their problems, the solutions to these problems became more apparent. The result has been a more consistent manufacturing practice that approaches the expected productivity and on-time delivery of this particular component to the M1 tank.

During this time period, substantial cost savings have been effected in the purchase as well as in the inventory control of cutting tools. This has been an immediate payback of this contract, making Metcut's work somewhat unique in its ability to demonstrate immediate implementation of contract objectives.

During May 1982, several trips were made to the Avco facility to contribute to the fact-finding effort of a "should cost" team that was evaluating the production of the gas turbine engine for the M1 tank. A report on Metcut's involvement in the "should cost" evaluation was delivered to TACOM at the designated end of that short term project.

Some of the tap manufacturers, supplying tools to Avco, were not being conscientious regarding the exactness of the class or pitch diameter limits on the taps. Variation of these limits would result in a quality problem of the tapped thread. Several tests were performed on a variety of taps to verify whether these taps were of the quality they were supposed to be. These results were reported to Avco.

An accelerated program on an experimental armor which was shipped to Metcut by TACOM was also performed late in 1982 and early in 1983. This experimental armor, a section of plate was approximately 1" thick and was designated as Armor X. Machining tests were performed on this material and a special report summarizing the results was delivered to TACOM.

6.0 TESTING EQUIPMENT

6.1 Turning and Boring

All of the turning tests were conducted on a LeBlond heavy duty lathe, 16 in. x 54 in., equipped with a 30 hp DC variable speed drive, see Figure 6-1. The spindle rpm could be varied to maintain the required cutting speed for any workpiece diameter. All types of carbide, coated carbide and ceramic cutting tools in indexable-insert form could be used with this machine tool. Boring tests were performed on another LeBlond lathe of the same size which was owned by the U. S. Government. This lathe was furnished specifically for work on this contract; however, this machine was not in good condition and did require a great deal of extra maintenance and repair. Consequently the machine was used only on the boring tests; it was not used for any of the turning tests. The regular AC motor was disconnected on this lathe and a 30 hp variable speed drive was temporarily connected to the machine tool so that variable speed boring could be performed. The rpm could be exactly set to accommodate any size diameter of the cut or testing at constant cutting speed.

6.2 Face Milling and End Milling

The face milling and end milling tests were performed on a Cincinnati #5 vertical dial-type milling machine, Figure 6-2. This machine is equipped with variable speed drive on both the spindle and the table so that exact levels of rpm and table feed can be set to accurately control the machining conditions. The workpieces were of varying size and shape because a variety of scrap pieces and other work material were obtained for this program. Different clamping techniques were necessary. Usually the workpieces were firmly held in a large heavy duty milling vise. Various types of set-ups could be used in both face milling and end milling. The sketches of the set-ups for different conditions of milling are shown in Figures 6-3 and 6-4.

The drilling and reaming tests were performed on two machines. The first machine was a single-spindle Avey box column drilling machine, Figure 6-5. This machine was equipped with a 2 hp variable speed drive and a variable feed drive. It was a nominal 25 in. machine with a maximum spindle speed of approximately 4500 rpm. The other machine was a Gidding & Lewis Bickford single spindle box column drilling machine, Figure 6-6. This machine had a 5 hp variable speed spindle drive. The feed rate was controlled by a two-stage gear box and had discrete feed rates. This machine was also equipped with a reversing spindle control for use in tapping.

The grinding tests were performed on a Norton 8 in. x 24 in. hydraulic surface grinder equipped with a 2 hp variable speed spindle drive, Figure 6-7. A vice clamped on a magnetic table was used to hold the various test specimens which were of different cross-sectional size and length. The specimens were clamped in the vice in such a way that the thickness measurements could be made without removing the specimen from the vice. The effects of grinding conditions on the grinding ratio of various materials were evaluated. The grinding ratio (G ratio) is a measure of grinding wheel life, (analogous to tool life in other machine operations) and is defined as $G = \frac{\text{volume metal removed}}{\text{volume wheel removed}}$. A wheel size of 10 in. x 1 in. x 3 in. was used for all the tests.

Before the grinding tests were started, a 30 in.-deep-by-1/2 in.- wide step was dressed in the grinding wheel. The step was used as a reference for measuring wheel wear. A 0.0001" dial indicator mounted on a fixture attached to the wheel housing was brought in contact with this step and the indicator was set to read 0. The indicator was then moved to the upper step or grinding surface of the wheel and the initial reading of the wheel diameter was taken. Indicator readings were taken after 0.025" or after 0.050" of metal was removed. The difference between the initial indicator reading and successive readings was a measure of the radial wheel wear. The initial outside diameter of the wheel was accurately measured before each test with a Vernier caliper. The volume of the wheel removed was calculated from the initial and final wheel diameters. Grinding ratios were calculated corresponding to various amounts of stock removal depending on the difficulty of grinding the particular alloy.

Figure 6-1. LeBlond Heavy Duty Lathe

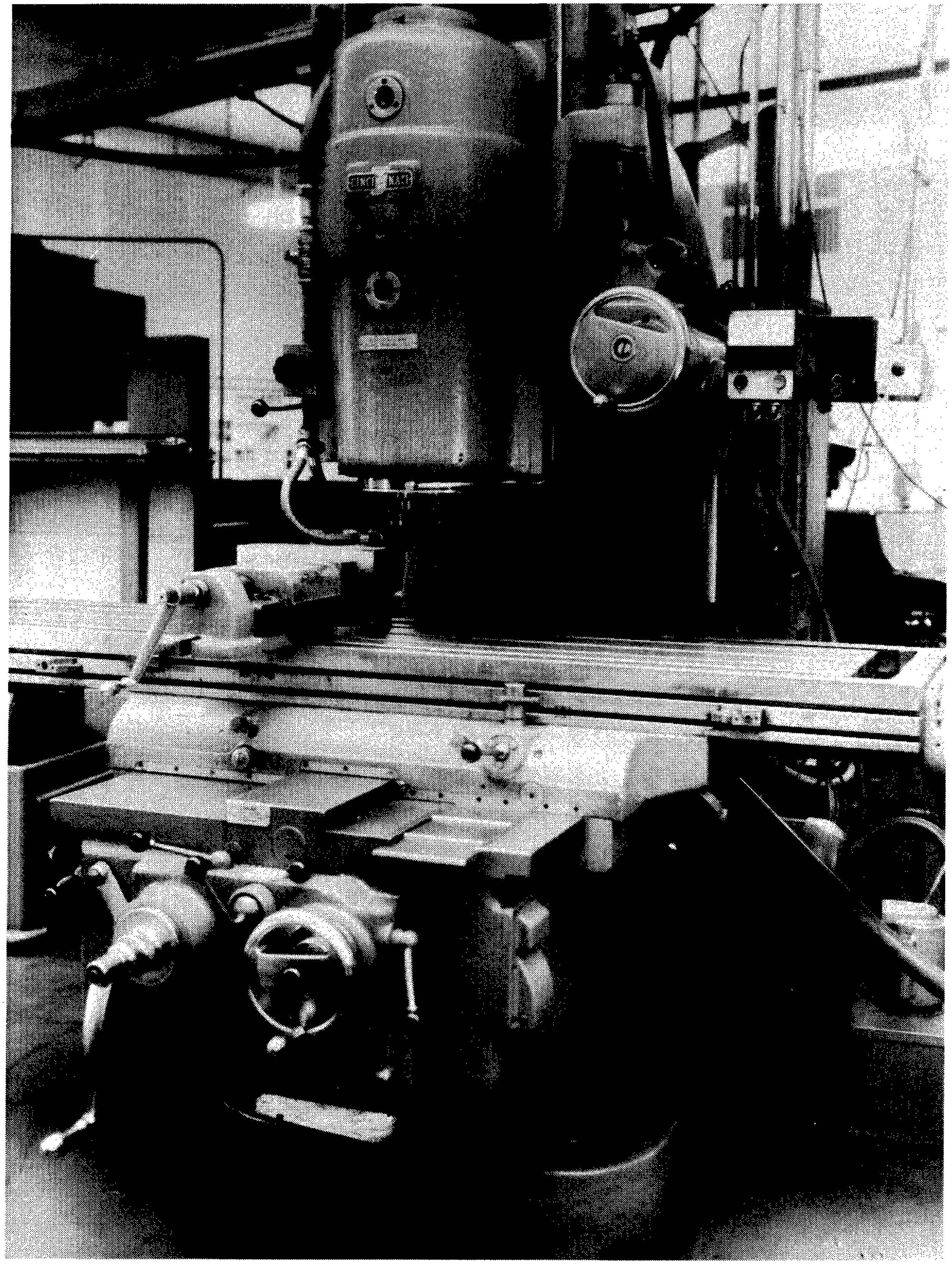


Figure 6-2. Cincinnati #5 Vertical Milling Machine

FACE MILLING SETUPS
ILLUSTRATING UP AND DOWN MILLING

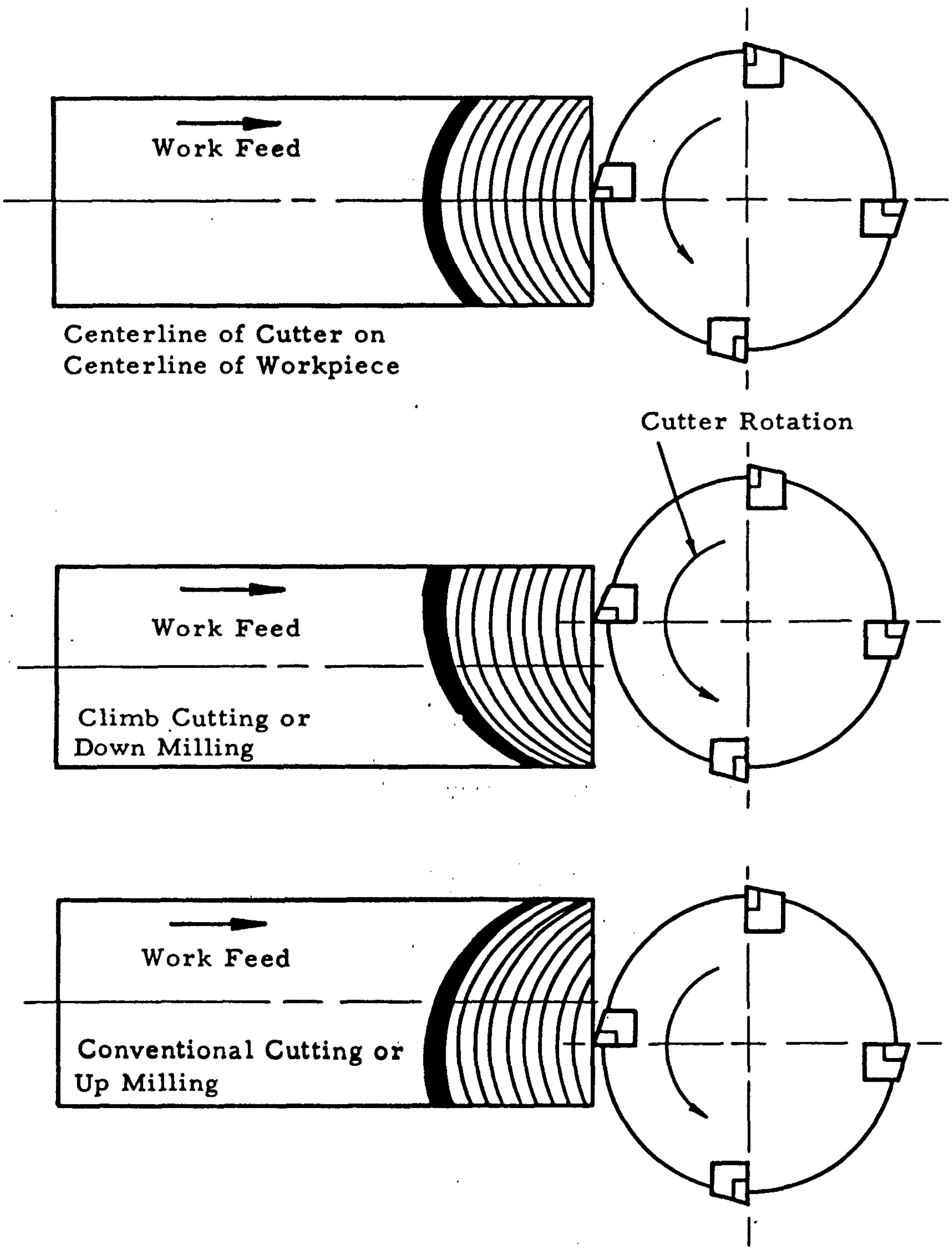


Figure 6-3. Face Milling Set-Ups

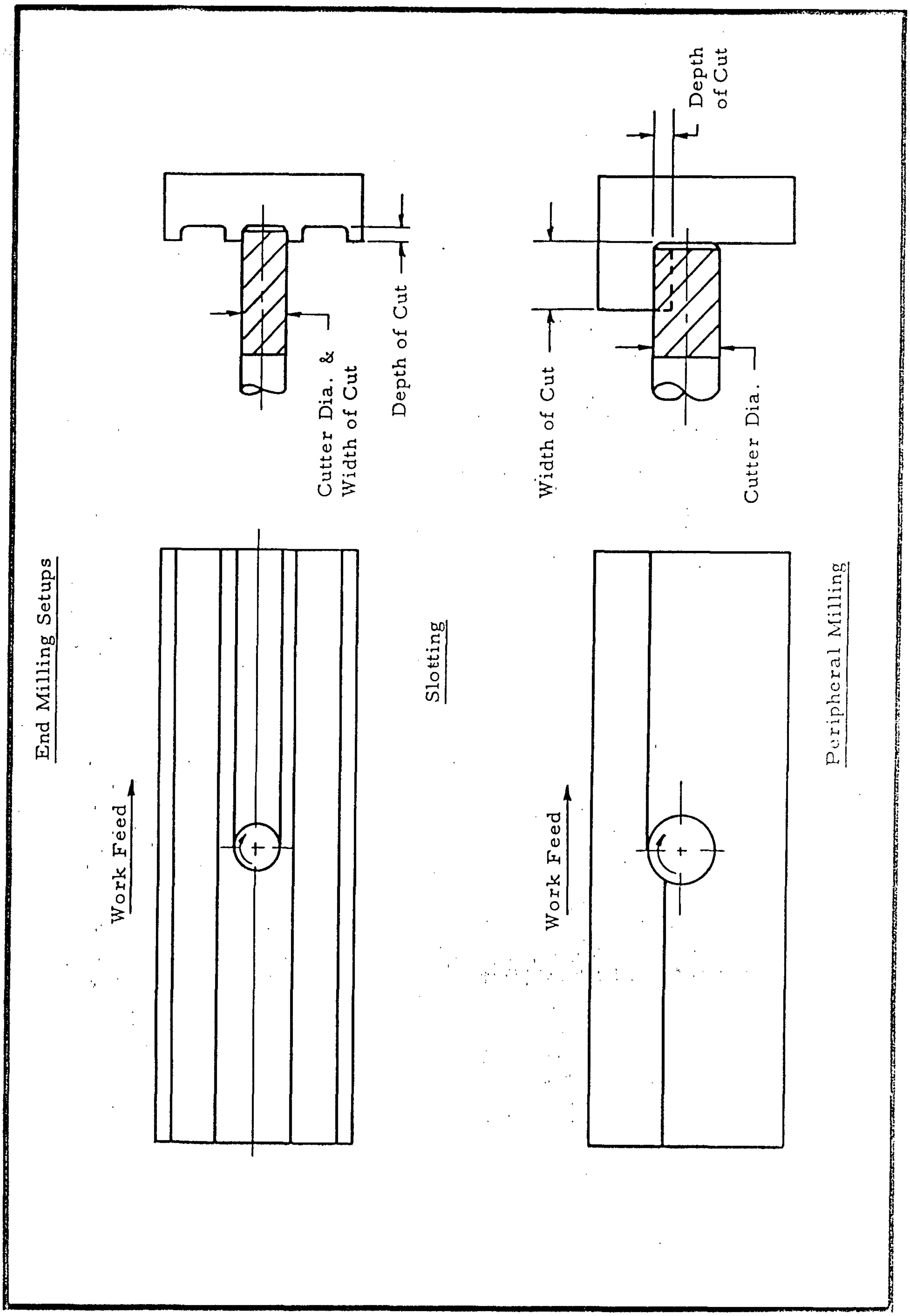


Figure 6-4. End Milling Set-Ups

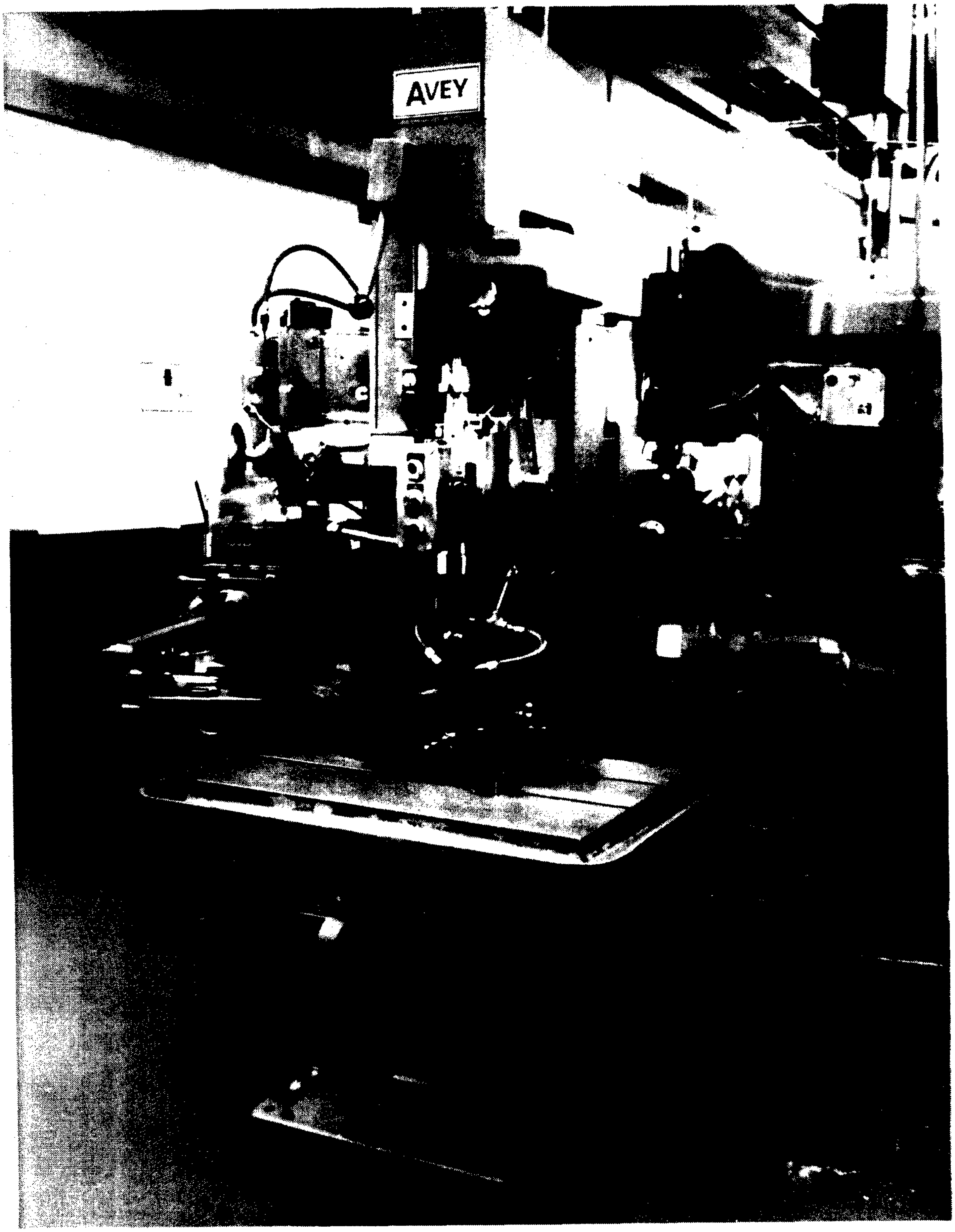


Figure 6-5. Avey Box Column Drilling Machine

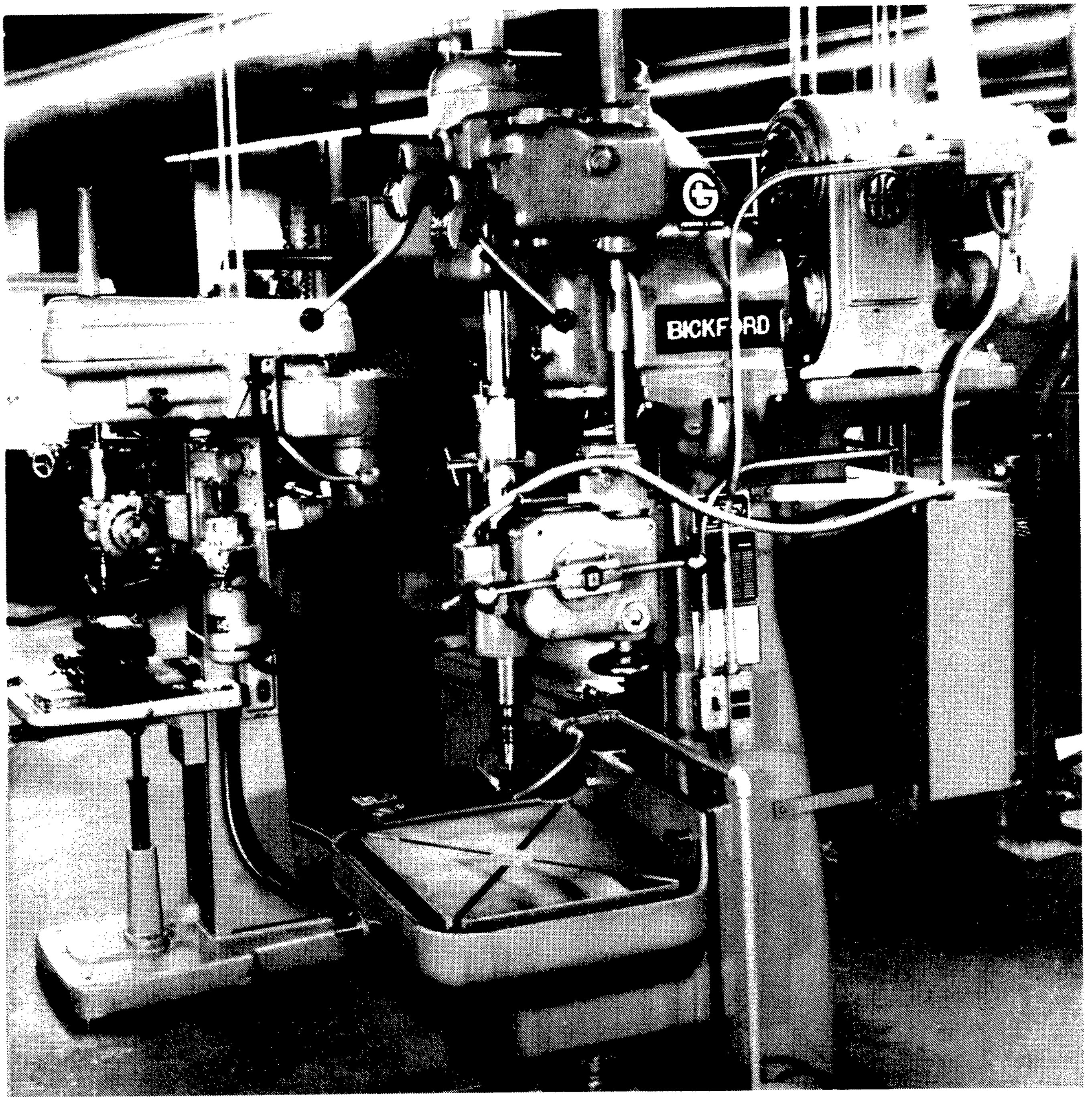


Figure 6-6. Gidding & Lewis Bickford Milling Machine

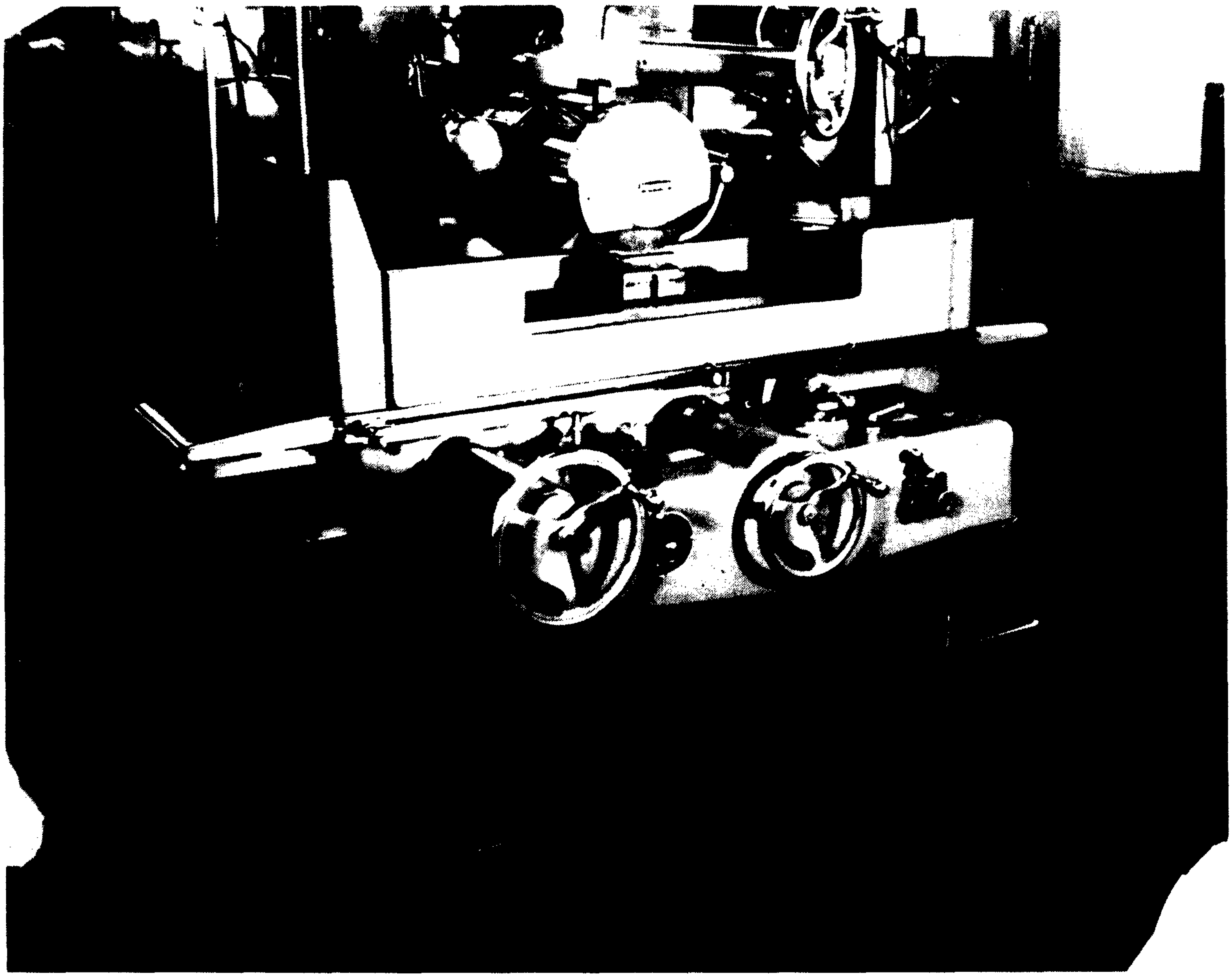


Figure 6-7. Norton Hydraulic Surface Grinder

7.0 WORK MATERIALS

The following descriptions provide details of the microstructure of the work materials machined in this program. TACOM provided two experimental armors. The first group was supplied at the start of the program and was called experimental armor. The second was supplied later in the program and was called Armor "X".

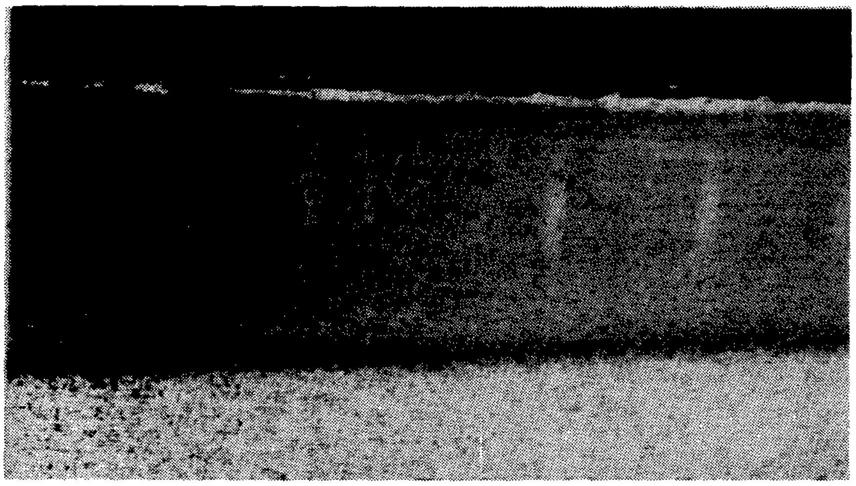
Many of the tank parts made of rolled armor plate are flame-cut and welded, such as the hull of the tank. Whenever a material is flame-cut and high temperatures are present, the material will probably have a heat-affected zone, adjacent to the flame-cut edge. Figure 7-1 shows this heat-affected zone produced in the first experimental armor supplied by TACOM. Heat-affected zone consists of three distinct levels. The surface consists of a thin layer of untempered martensite. The intermediate layer consists of self-tempered or over-tempered martensite. The third level, or the core of the material consists of normal-tempered martensite. The microstructure of the second experimental armor, known as Armor "X" is shown in Figure 7-2. This armor had a hardness of 50 Rc and a microstructure consisting of tempered martensite.

At the Lima Tank Plant, two types of armor were machined. The hull and turret were produced using rolled armor steel plate, while the torsion bar housing and other parts were made of cast armor steel. Two shipments of scrap armor plate pieces were received. The microstructures of samples from the two shipments are shown in Figures 7-3 and 7-4. Both microstructures are the same and show the characteristic heat-affected zone produced during the flame-cutting operation. The surface consisted of untempered martensite, the intermediate layer of over-tempered martensite and the core of normal-tempered martensite. The microstructure of the cast armor is shown in Figure 7-5. This microstructure consists of tempered martensite.

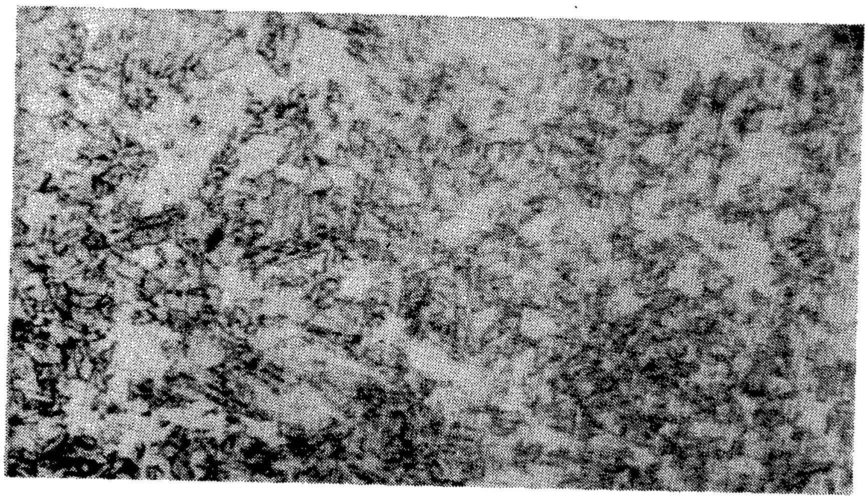
Two additional alloys used in the track and suspension on tracked combat vehicles are 4140 steel and 4350 steel. The 4140 steel was machined at the 32-35 Rc hardness range, and the 4350 steel at about 50 Rc. The microstructure of the 4140 steel is shown in Figure 7-6 and consists of tempered martensite with small areas of ferrite. The microstructure of the 4350 steel is shown in Figure 7-7 and consists of tempered martensite.

Three of the alloys which are used in the gas turbine engine are cast 17-4PH stainless steel, Inconel 718 and Inconel 713. The 17-4PH stainless steel was machined in the solution treated and aged condition. The microstructure as shown in Figure 7-8, consists of tempered martensite.

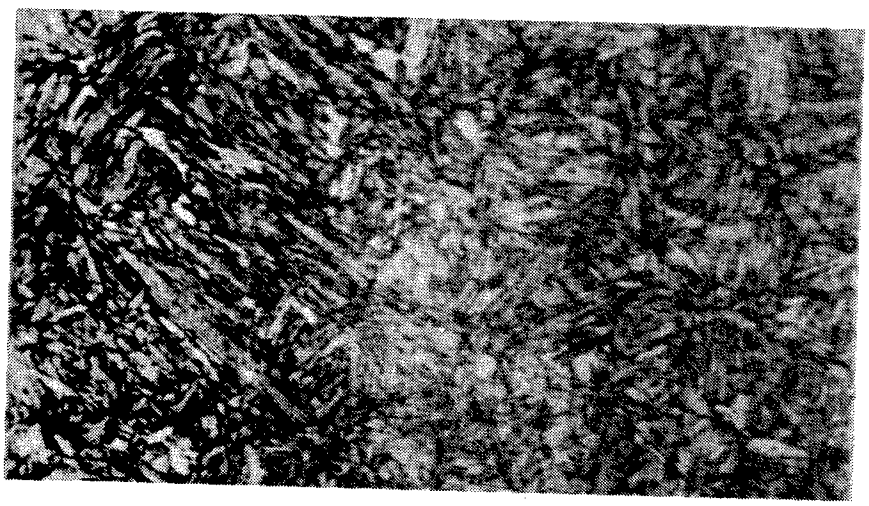
The microstructure of the Inconel 713, shown in Figure 7-9, consists of a dendritic pattern, typical of an as-cast material with the matrix of gamma solid solution and "script" pattern carbide particles. Figure 7-10 shows the microstructure of the Inconel 718. This microstructure consisted of a dispersed precipitate in a gamma solid solution matrix.



a) Overall Microstructure MAG: 10X



b) Microstructure of Heat Effected Zone MAG: 1000X



c) Microstructure of Core Material MAG: 1000X

Figure 7-1. Microstructure of TACOM Experimental Armor

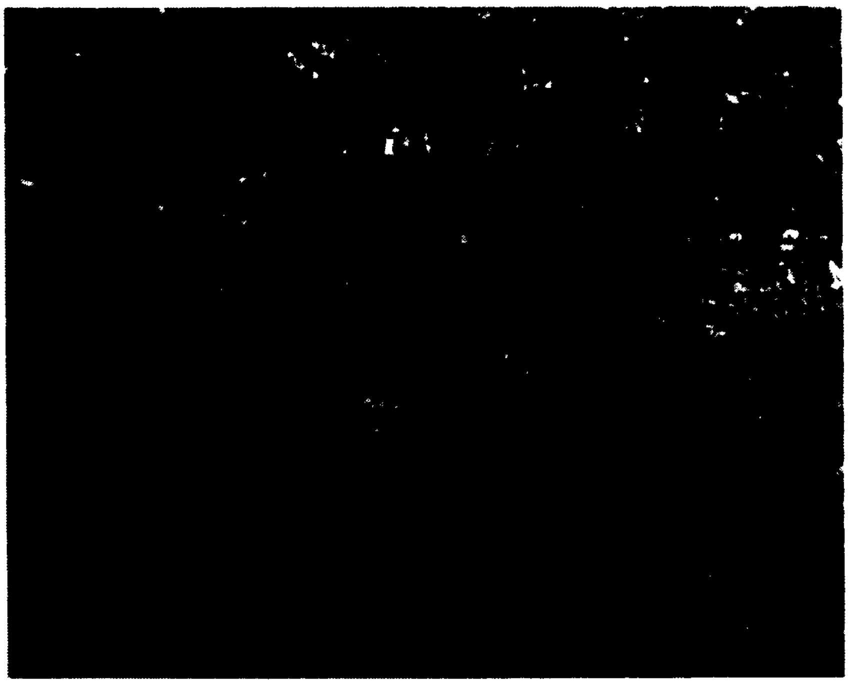


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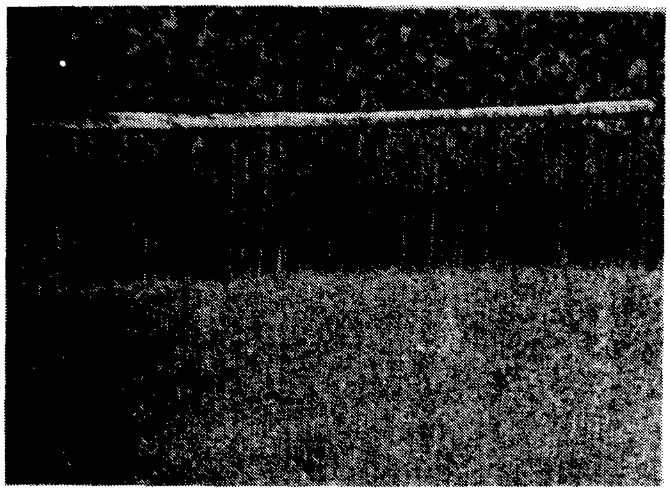
Figure 7-2. Microstructure of the Experimental Armor From TACOM Called Armor X

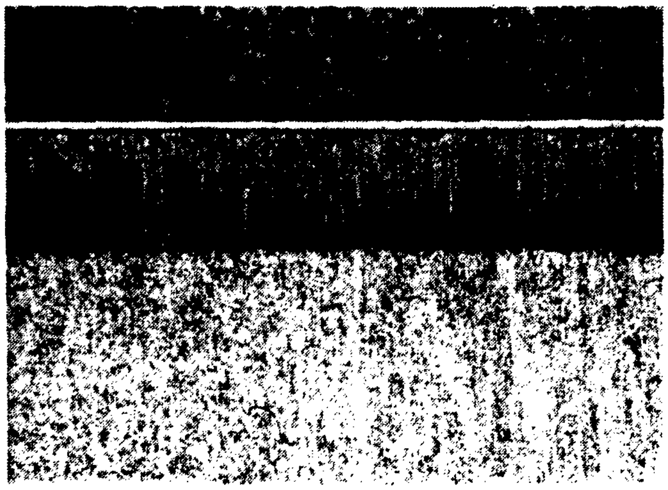


a) Overall Microstructure of Heat Effected Zone MAG: 10X

b) Microstructure of Heat Effected Zone MAG: 1000X

c) Microstructure of Core Material MAG: 1000X

Figure 7-3. Microstructure of Armor Plate Machined at the Lima Tank Plant



MAG: 10X

a) Overall Microstructure of Heat Effected Zone

MAG: 1000X

b) Microstructure of Heat Effected Zone

MAG: 1000X

c) Microstructure of Core Material

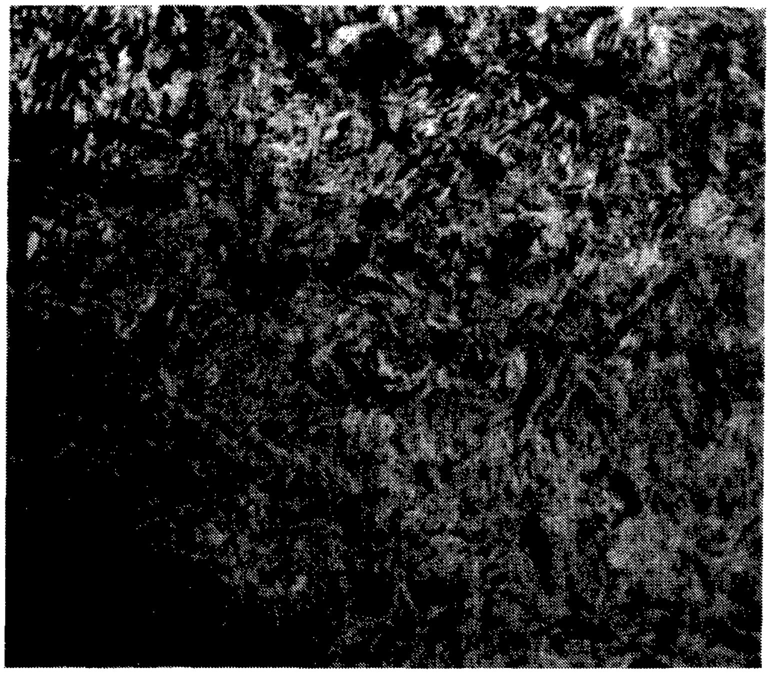
Figure 7-4. Microstructure of Armor Plate Machined at the Lima Tank Plant

MAG: 1000X

Figure 7-5. Microstructure of the Cast Armor Machined at the Lima Tank Plant

MAG: 1000X

Figure 7-6. Microstructure of 4140 steel 32-35 Rc



MAG: 1000X

Figure 7-7. Microstructure of 4350 Steel 50 Rc

MAG: 200X

Figure 7-8. Microstructure of 17-4 PH Stainless Steel

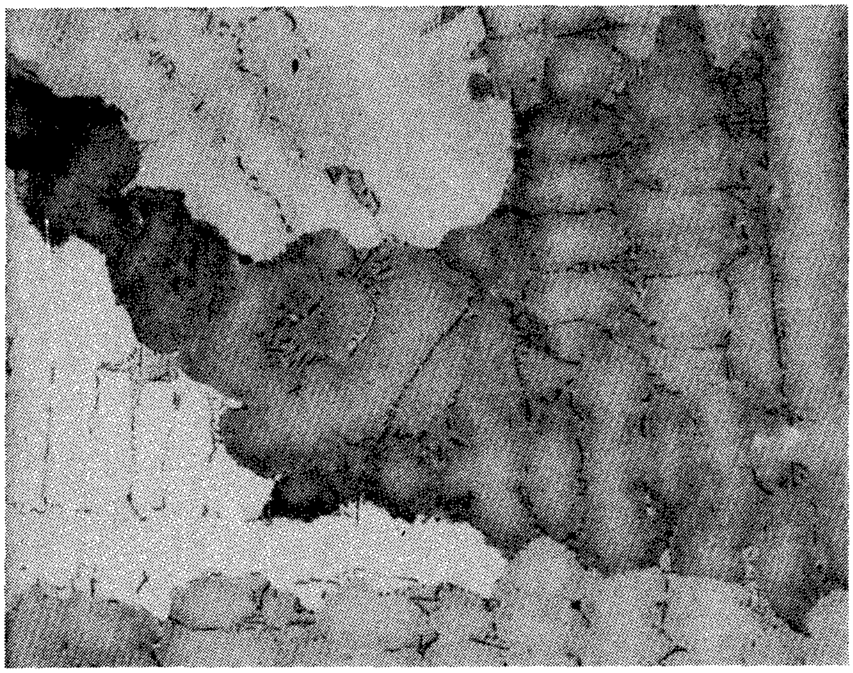


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Figure 7-9. Microstructure of Inconel 713

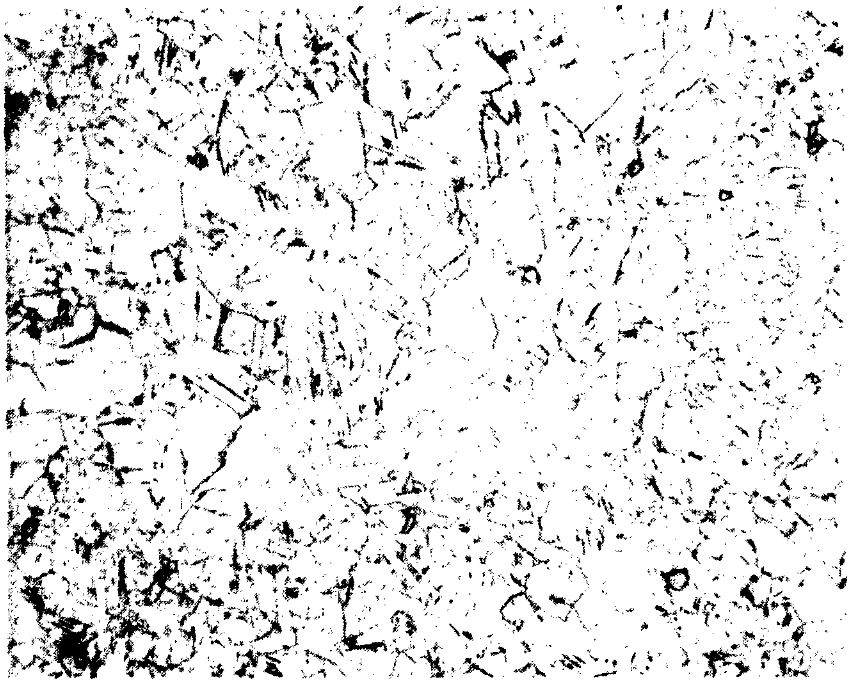

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Figure 7-10. Microstructure of Inconel 718

8.0 ECONOMICS OF MACHINING

When machining any component, it is first necessary to satisfy quality specifications such as surface finish, accuracy and surface integrity. When machining a part within the quality specifications, there usually exists a wide latitude of speeds, feeds, tool materials and other machining conditions which can be used for machining the component on a given machine tool. The objective of the manufacturing engineer is to select a set of machining parameters which, first, satisfy the quality specifications and, second, provide either minimum cost per piece or maximum production rate, or some combination of both.

This discussion describes methods for calculating the cost and production rates for any set of machining conditions used on a variety of machine tools. It also describes how to determine the conditions which provide minimum cost or maximum production rate. In order to make these various calculations, simple equations have to be applied relating the pertinent machining characteristics such as speed, feed, tool life, etc. Most of the equations are quite simple in themselves, such as the relationship between cutting speed and rpm of a cutter. However, the overall cost and production rate involves a combination of many of these simple equations. The arithmetic then becomes quite detailed and, for any extensive work in a cost and production analysis, it is logical to employ a computer or programmable calculator to relieve the monotony of the calculations.

The total cost for machining is made up of costs associated with operating the machine tool and costs associated with the cutter and its reconditioning. The machine tool cost can, in turn, be broken down into idle cost and machining or feeding cost. The idle cost, which consists of rapid traverse, load and unload and tool change costs, remains constant with change in cutting speed, while the machining cost decreases with increasing speed as shown in Figure 8-1. The tool reconditioning cost generally increases with increasing speed because the cutter wear rate is greater at higher speeds. The total cost is the sum of all of the above cost elements. This total cost is seen to go through a minimum at some intermediate cutting speed. In like manner, it is found that the production rate in pieces per hour increases with increasing cutting speed and goes through a maximum, Figure 8-1.

Although the previous discussion has centered on the relationship of cost to cutting speed, it should be pointed out that cost is also a function of other machining parameters, such as feed, depth of cut, width of cut, tool material, cutting fluid, etc. A method of calculating the machining cost and productivity for a specific operation will be given later.

Machinability data relating tool life to machining parameters must be obtained for the work materials that are to be machined. These data can be obtained either from handbooks, from historical shop experience, or machinability laboratory tests. It is important to have a well-defined format for recording and storing significant data. Typical formats giving the results of machining tests at the Metcut laboratory are shown in Tables 8-1, 8-2 and 8-3, for turning, milling, drilling, reaming and tapping.

The data requirements for determining cost and production rate may be divided into two types. The first type consists of the machining parameters; the second consists of time study and cost data. Examples of the first type of data, relating tool life to machining parameters, are shown in Tables 8-1, 8-2, and 8-3. A format illustrating the time study and cost data required for calculation of cost and production rate in turning is given in Table 8-4. A set of unified symbols that are required for these calculations is given in Table 8-5. These symbols apply to all five of the indicated machining operations.

The total cost in machining is the sum of a series of costs which can be divided into two sections: (a) the machine cost and (b) the tool re-reconditioning cost. The machine tool cost is determined by multiplying the labor and overhead rate of the machine tool, M, by the individual elements of time that comprise the total machine tool operation time. These time elements are as follows:

- feed time
- rapid transverse time
- load and unload time
- setup time
- tool change time

To this machine tool cost, one must add the tool reconditioning cost factors which include the following:

- tool depreciation cost
- tool resharpening cost
- rebrazing or blade reset cost
- insert or blade cost
- grinding wheel cost

Equations have been derived for calculating all of these time and cost elements, and when summed up they enable one to determine the overall cost per piece of an operation. Typical equations for the cost per piece in turning and milling are given in Figures 8-2 and 8-3. The derivation of the terms in the cost equations for turning and milling are displayed in Table 8-6. Similar equations for determining the cost have been developed for drilling, reaming and tapping and are shown in Figure 8-4. The production rate in pieces per hour for the same operations is 60 divided by the total time on the machine tool. The production rate equations for the same operations are given in Figure 8-5.

The following example in turning illustrates how the cost and production rates can be calculated. Table 8-4 gives the time study and cost data for turning a shaft 3.5 in. in diameter by 19 in. long. The material was 4340 steel, quenched and tempered to 300 Bhn. Three types of tools (i.e., brazed carbide tools, indexable insert carbide tools and high speed steel tools) are used for the cost investigations. The tool life data are given in Table 8-7. The data sets are denoted by the encircled numbers 1, 2, 3, and 4 for a C-7 carbide tool material and 5, 6, 7, 8 for high speed steel tool material.

The lathe tool setup for turning using the brazed carbide, the indexable carbide and the solid high speed steel tool is illustrated in Figure 8-6.

Using the above data, equation 1 of Figure 8-4 and equation 5 of Figure 8-5, the machining cost and production rate were determined. The calculations were performed on a computer, and a printout of the results is shown in Figure 8-7. Note that there are three sets of calculations: one for brazed carbide tools, one for indexable carbide tools and one for solid high speed steel tools. Using the tool life data for the C-7 carbide tool material and the time study data for brazed carbide tools, four cost calculations were made at each of four cutting speeds.

Note, that not only are the total cost per piece and the production rate in pieces per hour shown, but all the cost factors that make up the total cost. In the case of the brazed carbide tool, there were ten cost factors; for the indexable carbide tools, seven; and for the solid high speed steel, eight. A quick glance at the cost factors in Figure 8-7 indicates which are significant and which are insignificant. For example, with the brazed carbide tool when cutting at 470 feet per minute, the total cost was $5.33 per piece. Of this, the feeding cost was $1.50, the load and unload cost $0.92, the setup cost $0.42, the tool change cost $0.49, and the tool sharpening cost $1.48. The insignificant factors were as follows: rapid traverse cost $0.11, tool depreciation cost $0.13, rebrazing cost $0.16, tip cost $0.10, and the grinding wheel cost $0.02.

For the indexable carbide tools, Figure 8-7, it can be seen that all the tool costs were virtually nil. On the other hand, when turning with solid high speed steel, the tool cost was an appreciable portion of the total cost. Thus, when turning with high speed steel at 45 feet per minute, the total cost was $21.29 per piece, the tool change cost was $1.29, and the tool sharpening cost $2.58.

The cost and production rates for turning 4340 steel at 300 BHN are plotted against cutting speed in Figure 8-8 for brazed carbide, indexable carbide and high speed steel tools. It can be seen from the graph that the cost per piece decreased as the speed increased when using indexable carbide tools. The cost per piece was a minimum at approximately 360 feet per minute for the brazed carbide, and the cost per piece was a minimum at approximately 60 feet per minute for the high speed steel.

The minimum cost with the indexable carbide within the range of experimental data was about $3.09, with the brazed carbide $4.44, and with the high speed steel $18.62. The maximum production rate, also within the range of experimental data, was 8 pieces per hour for the throwaway carbide tools, 7 pieces per hour with the brazed carbide tools, and 1.8 pieces per hour with the high speed steel tools.

For those who would like to calculate the cost manually, the cost calculations for the same example in turning just described are given in Figure 8-9.

Figure 8-10 illustrates the types of cutters involved and indicates the length of the workpiece, the approach and overtravel of the milling cutter, the width of cut, and the diameter of the milling cutter. The cost and production rate in milling can be obtained from equation 2 of Figure 8-4 and equation 6 of Figure 8-5, respectively.

In the following example, the cost and production rates were determined for AISI 4340, quenched and tempered to 341 BHN. A 2-inch wide cut was taken on an 8-inch workpiece with 4-inch diameter milling cutters. A solid high speed steel cutter and two types of carbide cutters (inserted tooth and indexable insert) were used. The pertinent time study data required for the calculations are listed in Table 8-8.

The tool life data for the alloy 4340 are steel shown in Table 8-9. In this table, the sets of data relating tool life in inches per tooth to cutting speed in feet per minute for the alloy are numbered 1 through 6 for identification.

The computer was used to calculate the cost per piece from equation 2, Figure 8-4, and the production rate from equation 6, Figure 8-5. The computer printouts of the results are shown in Figure 8-11.

Examination of the computer printouts in Figure 8-11 reveals the significant cost factors and the comparative costs per piece and production rates among the types of tool used. For instance, in face milling 4340, the printouts show that the use of an indexable carbide insert cutter resulted in higher production and lower costs. This is more evident from examining the graph in Figure 8-12, which indicates that the cost per piece in face milling the 4340 steel did not vary as sharply for the indexable insert cutter as it did for the other cutters. The production rate curve for the indexable cutter lies above the other three types. Note that the data used in this example the minimum cost and maximum production rate occur for the case of indexable carbide insert cutters at 550 feet per minute.

Figure 8-13 illustrates the setup for drilling, reaming and tapping. Here also are shown the meaning of the diameter of Cutter, D, the approach of tool to work, a, the length of the workpiece, L, and the overtravel of tool past the workpiece, e. In this example, costs and production rates in drilling were determined for AISI 4340 steel, annealed to 212 BHN. High speed steel drills were used to drill five holes, a half-inch deep in each part. The drill diameter used was one-quarter of an inch. The time study data required are given in Table 8-10.

The tool life data are listed in Table 8-11. The sets of data giving the drill life in terms of number of holes are numbered 1 through 8. The cost and production equations required that the drill life (T_t) be expressed in inches. Therefore, it was necessary to multiply the drill life, in number of holes drilled, by the hole length to get the drill life in inches of travel to dull the drill. In data set 1, the drill life was 30 holes. The length of each hole was 0.5 in. The drill life, therefore, was T_t = 15 in. (20 x .5 in.).

Figure 8-14 is the computer printout of the results using equation 3, Figure 8-4, to calculate the cost per piece and equation 7, Figure 8-5, to determine the production rate.

Figure 8-15 shows the cost and production rate curves for this drilling operation.

It is evident that a feed of 0.005 in. per revolution can achieve higher production rates and lower costs than a feed of 0.002 in. per revolution, provided that proper cutting speeds are used.

Equations have been derived for determining the cost and production for NC machining. These equations and procedures can be obtained from the following two sources:

1. Machining Data Handbook, Third Edition. Metcut Research Associates Inc., 1980, Volume 2, pp. 21-1 to 21-44.

2. Determination and Analysis of Costs in N/C and Conventional Machining, A. Ackenhausen and M. Field, SME Technical Paper MR70-545.

It is possible to analytically determine the optimum machining conditions, that is, the conditions which produce either minimum cost of maximum production rate. The recommended procedure is first to obtain suitable tool life data as a function of speeds, feeds and the other machining conditions. Then these data, together with the corresponding time study and other shop information, are applied to the specific machining operation, and calculations of costs and production rates are made using the equations listed in Figures 8-4 and 8-5. The minimum cost and maximum production rate can be obtained from the computer printouts using the various shop data available. Of course, this technique requires the use of a computer to avoid the long, tedious hand calculations.

One of the major advantages of the computer printout procedure is that we have in the computer printout not only the total cost and the total production rate, but also the individual elements of cost which make up the total. The ability to visually scan over the cost elements of any machining operation is especially valuable. There is always a tendency for the tool engineer to try to reduce cost by reducing the time in cut, that is, the feeding time. However, in many cases, other elements of cost are more significant than the cost of actually producing chips. It is, therefore, important to examine all of the cost elements involved in each operation to determine which are trivial and which are significant and then reduce the cost of the major cost elements.

A complete analytical determination of optimum machining conditions can be obtained by using a mathematical relationship among the machining parameters, that is, among tool life and speed, feed, and depth of cut. The possibility of doing this accurately is excellent using current computer modeling techniques. A simple empirical equation can be derived relating these parameters with tool life.

When it is necessary to decrease cost or increase productivity of a machining operation, it is possible to experiment on the shop floor by changing machining conditions. Careful records should be kept of the changes in cutting conditions and the effect of these changes on tool life as well as production rates.

Usually, the first step is to increase the feed. The feed may be increased until either the specified surface finish is no longer obtained or the tool life starts to decrease. With the best feed, the next step is to increase and then decrease the cutting speed and observe the change in tool life. Where possible, the depth of cut can also be adjusted to affect metal removal rates. In this manner, the combination of feed, speed, and depth of cut can be selected to achieve maximum productivity. Additional factors that may be investigated for their effect on tool life include cutting tool material, tool geometry and cutting fluid.

Although the productivity as a result of shop changes can be readily observed, it is not possible to directly observe the effect of these changes on the overall machining cost. Machining cost involves not only machine tool time, but also the cutter cost. It is necessary, therefore, to calculate the overall machining cost and production rate as a function of the machining parameters using the procedure previously described.

Although the equations used for the cost and production rate calculations involve only simple mathematics, the detailed analysis of a given machining setup will become very time-consuming because many factors must be included. With this in mind, techniques have been developed that allow the rapid analysis of a machining operation through the use of computers and programmable calculators.

The cost and production rate equations shown in Figures 8-4 and 8-5 have been programmed in Fortran IV for use on a computer with as little as 8K words of memory. This program, called NCECO, is available through the Machinability Data Center and is supplied with full documentation. With minor modifications for input-output, this program will operate on any digital computer supporting the Fortran IV language. The program will accept any combination of machining operations required for a part setup including: turning, face milling, end milling, drilling, reaming, tapping, center drilling and chamfering. Capability exists to determine the effects of using various types of tools, i.e., high speed steel, brazed carbide or throwaway insert tools.

With the advent of programmable calculators, it is now possible to perform these calculations quickly without utilizing a computer. A calculator generally uses semiconductor electronics that allow the solving of a mathematical problem using a series of keystrokes on the machine. A programmable calculator has the ability to store and automatically execute the series of keystrokes necessary to solve a particular problem. Using this feature, a programmable calculator can be instructed to perform all the calculations necessary for cost and production rate analysis with the user supplying only the data necessary for the calculations. All output is by digital display. The programs are stored on small magnetic strips which are read by the machine simply by inserting a strip in a slot on the side of the machine. The small memory size of these machines makes it necessary to use a separate memory strip for each type of operation. The magnetic strips can be stored in a small card which gives all the necessary instructions for running a complete analysis. Since these calculators are pocket-sized, calculations may be performed right on the shop floor.

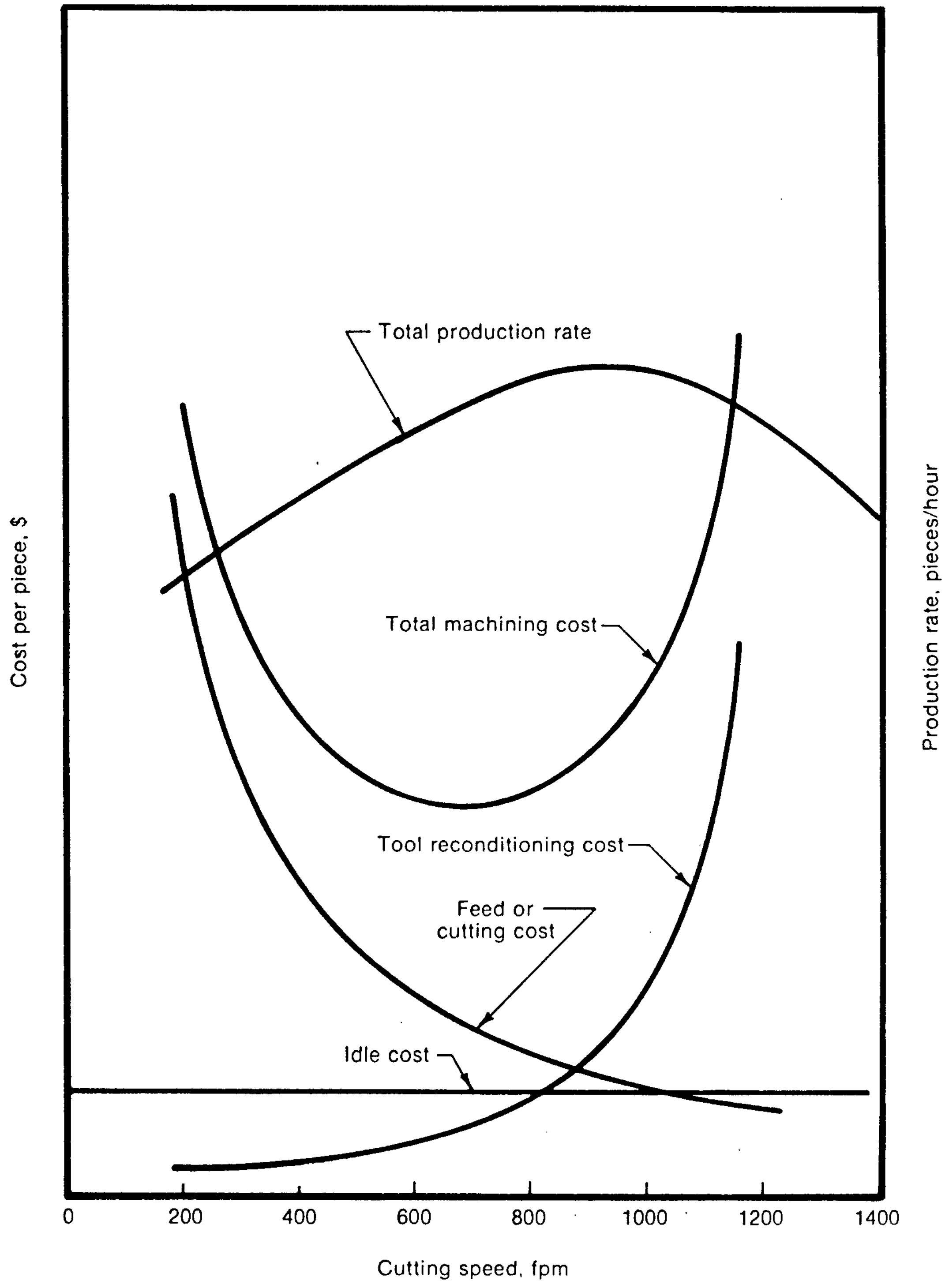


Figure 8-1. Machining Cost and Production Rate versus Cutting Speed.

Table 8-1. Machining Data Formats for Turning

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	TOOL MATERIAL Trade Name	TOOL MATERIAL Industry Grade	TOOL GEOMETRY BR°	SR°	SCEA°	ECEA°	Relief°	Nose Radius in	CUTTING FLUID CODE *	DEPTH OF CUT in	FEED ipr	TOOL LIFE END POINT in	TOOL LIFE, min vs CUTTING SPEED, fpm			
Alloy Steels 8640	Quenched and tempered	400	—	T1 HSS	0	15	0	5	5	0.005	11 1:20	0.060	0.009	0.060	5	15	30	
	Tempered martensite														80	67	58	
8640	Annealed	170	78	C-7	0	6	0	6	6	0.040	00	0.100	0.010	0.015	15	30	45	60
	50%P-50%F														610	490	420	373
8640	Spheroidized	180	78	C-7	0	6	0	6	6	0.040	00	0.100	0.010	0.015	15	30	45	60
	Spheroidized carbides + ferrite														695	580	525	485
8640	Annealed	190	78	C-7	0	6	0	6	6	0.040	00	0.100	0.010	0.015	15	30	45	60
	75%P-25%F														590	450	380	335
8640	Annealed	250	78B	C-6	0	6	0	6	6	0.040	00	0.100	0.010	0.015	1	6	20	66
	Widmanstätten														910	600	440	300
8640	Annealed	250	78	C-7	0	6	0	6	6	0.040	00	0.100	0.010	0.015	15	30	45	60
	Widmanstätten														640	520	440	375
8640	Quenched and tempered	300	78	C-7	0	6	0	6	6	0.040	00	0.100	0.010	0.015	5	15	20	
	Tempered martensite														660	400	315	
8640	Quenched and tempered	400	78	C-7	0	6	0	6	6	0.040	00	0.100	0.010	0.015	5	15	20	
	Tempered martensite														480	365	318	
52100	Spheroidized	190	—	T1 HSS	0	15	0	5	5	0.005	11 1:20	0.060	0.009	0.060	15	30	35	
	Spheroidized carbides + ferrite														137	123	120	
52100	Spheroidized	190	78B	C-6	0	6	0	6	6	0.040	00	0.100	0.010	0.015	15	30	45	
	Spheroidized carbides + ferrite														430	340	300	

*Cutting Fluid Code
00 Dry
11 Soluble Oil

Table 8-2. Machining Data Formats for Milling

FACE MILLING

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	TOOL MATL. Trade Name	TOOL MATL. Industry Grade	UP OR DOWN MILLING	TOOL GEOMETRY AR°	RR°	CA°	TR°	Incl°	ECEA°	End Rel.° / Cor. Rel.°	CUTTING FLUID CODE *	DEPTH OF CUT in	WIDTH OF CUT in	FEED PER TOOTH in	TOOL LIFE END POINT in	TOOL LIFE/TOOTH inches work travel vs CUTTING SPEED, fpm			
Stainless steels Martensitic 410	Quenched & tempered	353	370	C-6	Up	0	-7	45	-5	5	5	8	00	0.100	2.0	0.010	0.016	15	45	60	90
	Tempered martensite											8						540	420	365	230
410	Quenched & tempered	45 R_c	—	T15 HSS	Up	0	0	45	0	0	5	8	11 1:20	0.060	2.0	0.005	0.060	15	30	50	
	Tempered martensite											8						100	79	68	

END MILL SLOTTING

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	TOOL MATL. Trade Name	TOOL MATL. Industry Grade	CUTTER TYPE	DIA. in	NO. TEETH	FLUTE LENGTH in	UP OR DOWN MILLING	TOOL GEOMETRY Helix Angle°	RR°	Chamfer	ECEA°	End Rel.° / Periph. Rel.°	CUTTING FLUID CODE *	DEPTH OF CUT in	WIDTH OF CUT in	FEED PER TOOTH in	TOOL LIFE END POINT in	TOOL LIFE/CUTTER inches work travel vs CUTTING SPEED, fpm			
Alloy steel 4340	Annealed	213	—	M2 HSS	Solid HSS	0.750	4	2	—	30	10	45° x 0.060 in	1	3	11 1:20	0.250	0.750	0.002	0.012	50	120	240	
	Spheroidized carbides ferrite													7						190	153	125	

PERIPHERAL END MILLING

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	TOOL MATL. Trade Name	TOOL MATL. Industry Grade	CUTTER TYPE	DIA. in	NO. TEETH	FLUTE LENGTH in	UP OR DOWN MILLING	TOOL GEOMETRY Helix Angle°	RR°	Chamfer	ECEA°	End Rel.° / Periph. Rel.°	CUTTING FLUID CODE *	DEPTH OF CUT in	WIDTH OF CUT in	FEED PER TOOTH in	TOOL LIFE END POINT in	TOOL LIFE/CUTTER inches work travel vs CUTTING SPEED, fpm			
High strength steel D6ac	Annealed	223	—	M2 HSS	Solid HSS	0.750	4	2	Down	30	10	45° x 0.060 in	1	3	11 1:20 Mist	0.250	0.750	0.004	0.012	75	130	260	
	60% P-40% F													7						290	240	190	

*Cutting Fluid Code
00 Dry
11 Soluble Oil

Table 8-3. Machining Data Formats for Drilling, Reaming and Tapping

DRILLING

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	DRILL MATL. Trade Name	DRILL MATL. Industry Grade	TYPE DRILL	DRILL SIZE Dia. in	DRILL SIZE Length in	DRILL SIZE Flute Length in	DRILL GEOMETRY Type Point	DRILL GEOMETRY Helix Angle°	DRILL GEOMETRY Point Angle°	DRILL GEOMETRY Lip Relief°	CUTTING FLUID CODE *	DEPTH OF HOLE in	FEED ipr	DRILL LIFE END POINT in	DRILL LIFE no. of holes vs CUTTING SPEED, fpm				
Alloy steel 4340	Quenched & tempered	341	—	M2 HSS	Twist	0.250	4.0	2.75	Standard	29	118	7	31	0.5 thru	0.002	0.015	25	50	75	100	
	Tempered martensite																98	84	76	70	
"	"	"	—	"	"	"	"	"	"	"	"	"	"	"	0.005	"	25	50	75	100	
	"																80	65	56	50	

REAMING

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	REAMER DESCRIPTION TOOL MATL. Trade Name	TOOL MATL. Industry Grade	Dia. in	No. of Flutes	Style	TOOL GEOMETRY Helix & Hand	TOOL GEOMETRY Chamfer	TOOL GEOMETRY Rel.°	CUTTING FLUID CODE *	STOCK ALLOW. ON DIA. in	LENGTH OF HOLE in	FEED ipr	TOOL LIFE END POINT in	REAMER LIFE no. of holes vs CUTTING SPEED, fpm				
High strength steel 250 Grade maraging steel	Annealed & maraged	50 R_c	—	M2 HSS	0.272	6	Chucking	0° RH	45° x 0.060 in	7	52	0.022	0.5 thru	0.005	0.006	20	35	170		
	Martensite															90	80	50		

TAPPING

MATERIAL	CONDITION AND MICROSTRUCTURE	HARDNESS Bhn	TAP MATERIAL	TAP SIZE	NO. OF FLUTES	TAP STYLE	PERCENT OF THREAD	CUTTING FLUID CODE *	DEPTH OF HOLE in	TAP LIFE END POINT in	TAP LIFE no. of holes vs CUTTING SPEED, fpm				
High temperature alloy—iron base, wrought A-286	Solution treated & aged	320	M10 HSS	5/16-18NC	2	Plug spiral point	75	53	0.5 thru	Tap breakage	12	31	132		
	Austenitic										50	40	30		

*Cutting Fluid Code
31 Sulfurized mineral oil + fatty oil—light duty
52 Sulfo-chlorinated mineral oil + fatty oil—medium duty
53 Highly chlorinated mineral oil—heavy duty

Table 8-4. Example of Data for Turning Operation

Operation: Turn shaft, 3.5" diameter by 19" long Material: 4340 Steel, Q&T, 300 Bhn	Brazed Carbide Tool	Throwaway Carbide Tool	Solid HSS Tool
a = approach of tool to work, in.	4.0	4.0	4.0
C_c = cost of each carbide tip or insert, $	5.00	3.15	--
C_p = purchase cost of tool, $	6.70	28.30	18.30
C_w = cost of grinding wheel for resharpening tool, $	.07	--	.02
d = depth of cut, in.	.1	.1	.1
D = diameter of work in turning, in.	3.5	3.5	3.5
f_r = feed per revolution, in./rev.	*	*	*
G = labor and overhead cost on tool grinder, $/min.	.40	--	.40
k_1 = no. of times lathe tool is resharpened before discarding (or no. times insert is indexed before throwaway holder is discarded)	12	2000	36
k_2 = no. of times lathe tool is resharpened before rebrazing or resetting	6	--	--
k_3 = no. of times insert is resharpened (or indexed) before insert is discarded	12	8	--
L = length of workpiece in turning, in.	19	19	19
M = labor and overhead cost on lathe, $/min.	.40	.40	.40
N_l = no. of pieces in lot	20	20	20
r = rapid traverse rate, in./min.	100	100	100
t_b = time to rebraze lathe tool, min.	10	--	--
t_c = time to change and reset tool or time to index throw-away insert, min.	5	.4	5
t_l = time to load and unload workpiece, min.	2.3	2.3	2.3
t_o = time to set up lathe for operation, min.	21	21	21
t_s = time to resharpen tool, min.	15	--	10
T = tool life, total time to dull tool, min.	*	*	*
v = cutting speed, ft./min.	*	*	*
e = extra travel of tool in feed (includes approach and overtravel in feed)	.2	.2	.2

* These values are taken from Tool Life Data, Table 8-7.

Table 8-5. Symbols for Cost and Production Rate Equations

Symbol	Definition	Applies to Operation			
		Turn	Mill	Drill & Ream	Tap
a	approach of tool to work; in.	✓	✓	✓	✓
C	total cost for machining one workpiece; $/workpiece	✓	✓	✓	✓
C_a	carbide tip cost per workpiece; $/workpiece	✓	✓	No	No
C_c	cost of each insert or inserted blade; $/blade	✓	✓	No	No
C_d	tool depreciation cost per workpiece; $/workpiece	✓	✓	✓	✓
C_p	purchase cost of tool or cutter; $/cutter	✓	✓	✓	✓
C_w	cost of grinding wheel for resharpening tool or cutter; $/cutter	✓	✓	No	No
d	depth of cut; in.	✓	✓	No	No
D	dia. of work in turning, of tool in milling, drilling, reaming, tapping; in.	✓	✓	✓	✓
e	overtravel of milling cutter past workpiece; in.	No	✓	No	No
f_r	feed per revolution; in. / rev.	✓	No	✓	No
f_t	feed per tooth; in. /tooth	No	✓	No	No
G	labor + overhead on tool grinder; $/min.	✓	✓	✓	✓
k_1	no. of times lathe tool, or milling cutter, or drill, or reamer is resharpened before being discarded	✓	✓	✓	✓
k_2	no. of times lathe tool or milling cutter is resharpened before inserts or blades are rebrazed or reset	✓	✓	No	No
k_3	no. of times blades (or inserts) are resharpened (or indexed) before blades (or inserts) are discarded	✓	✓	No	No
L	length of workpiece in turning and milling or sum of lengths of all holes of same diameter in drilling, reaming, tapping; in.	✓	✓	✓	✓
m	no. of threads per inch	No	No	No	✓
M	labor + overhead cost on lathe, milling machine or drilling machine; $/min.	✓	✓	✓	✓
n	tool life exponent in Taylor's Equation	✓	✓	✓	✓
N_b	no. of workpieces turned or milled or drilled per brazing or resetting	✓	✓	No	No
N_L	no. of workpieces in lot	✓	✓	✓	✓
N_s	no. of workpieces turned, milled, drilled, reamed or tapped per resharpening	✓	✓	✓	✓
P	production rate per 60 min. hour; workpieces/hr.	✓	✓	✓	✓
r	rapid traverse rate; in. /min.	✓	✓	✓	✓
S	reference cutting speed for a tool life of T = 1 min. ; ft. /min.	✓	No	No	No
S_c	reference cutting speed for a tool life of T_c = 1 cubic inch; ft. /min.	No	✓	No	No
S_t	reference cutting speed for a tool life of T_t = 1 inch; ft. /min.	No	✓	✓	✓
t_b	time to rebraze lathe tool or cutter teeth or reset blades; min.	✓	✓	No	No
t_c	time to change tool or index all inserts in cutter; min. /cutter	✓	✓	✓	✓
t_L	time to load & unload workpiece, min.	✓	✓	✓	✓
t_m	floor to floor time to turn or mill one workpiece; or to drill, ream or tap all holes of same diameter in one workpiece; min.	✓	✓	✓	✓
t_o	time to setup machine tool for operation; min.	✓	✓	✓	✓
t_s	time to resharpen lathe tool, milling cutter, drill, reamer or tap; min. /tool	✓	✓	✓	✓
T	tool life measured in minutes to dull a lathe tool, min.	✓	No	No	No
T_c	tool life measured in cubic inches to dull a lathe tool, drill, reamer, tap or one milling cutter tooth; cu. in.	✓	✓	✓	✓
T_t	tool life measured in inches travel of work or tool to dull a drill, reamer, tap or one milling cutter tooth; in.	No	✓	✓	✓
u	no. of holes of same diameter in workpiece	No	No	✓	✓
v	cutting speed; ft. /min.	✓	✓	✓	✓
w	width of cut; in.	No	✓	No	No
W	grinding wheel cost to sharpen tool or cutter; $/cutter	✓	✓	✓	✓
Z	no. of teeth in milling cutter or no. of flutes in a tap	No	✓	No	No

BRAZED CARBIDE TOOL

$$C = \underbrace{\underbrace{M}_{\text{\$/MIN}}\underbrace{\left[\underbrace{\frac{DL}{3.82 f_r v}}_{\text{FEEDING TIME}} + \underbrace{\underbrace{\frac{2a + L + e}{r}}_{\text{RAPID TRAVERSE TIME}} + \underbrace{t_l}_{\text{LOAD \& UNLOAD TIME}} + \underbrace{\frac{t_o}{N_l}}_{\text{SETUP TIME}}}_{\text{Idle Time on Lathe}} + \underbrace{\frac{DLt_c}{3.82 f_r v T}}_{\text{TOOL CHANGE TIME}}\right]}_{\text{Total Time on Lathe}}}_{\text{Total Machine Time Cost}} + \underbrace{\frac{DL}{3.82 f_r v T}\left[\underbrace{\frac{C_p}{(k_1 + 1)}}_{\text{TOOL DEPRECIATION COST}} + \underbrace{G t_s}_{\text{TOOL RESHARPENING COST}} + \underbrace{\frac{G t_b}{k_2}}_{\text{REBRAZING COST}} + \underbrace{\frac{C_c}{k_3}}_{\text{CARBIDE TIP COST}} + \underbrace{C_w}_{\text{GRINDING WHEEL COST}}\right]}_{\text{Total Tool Cost}}$$

Figure 8-2. Cost per Piece in Turning.

INSERTED TOOTH CUTTER - CARBIDE TIP OR HSS BLADE

$$C = \underbrace{\underbrace{M}_{\$/\text{MIN}} \underbrace{\left[\underbrace{\frac{D(e+L)}{3.82\, Z f_t v}}_{\text{FEEDING TIME}} + \underbrace{\underbrace{\frac{2a+e+L}{r}}_{\text{RAPID TRAVERSE TIME}} + \underbrace{t_L}_{\text{LOAD \& UNLOAD TIME}} + \underbrace{\frac{t_o}{N_L}}_{\text{SETUP TIME}}}_{\text{Idle Time on Mill}} + \underbrace{\frac{L\, t_c}{Z\, T_t}}_{\text{CUTTER CHANGE TIME}} \right]}_{\text{Total Time on Mill}}}_{\text{Total Machine Time Cost}} + \underbrace{\frac{L}{Z\, T_t} \left[\underbrace{\frac{C_p}{(k_1+1)}}_{\text{CUTTER BODY DEPRECIATION COST}} + \underbrace{G\, t_s}_{\text{CUTTER RESHARPEN COST}} + \underbrace{\frac{G\, t_b}{k_2}}_{\text{BLADE RESET COST}} + \underbrace{\frac{Z\, C_c}{k_3}}_{\text{BLADE COST}} + \underbrace{C_w}_{\text{GRINDING WHEEL COST}} \right]}_{\text{Total Cutter Cost}}$$

Figure 8-3. Cost Per Piece in Face Milling and End Milling.

Turning

$$C = M\left[\frac{D(e+L)}{3.82 f_r v} + \frac{2a+e+L}{r} + t_l + \frac{t_o}{N_l} + \frac{DLt_c}{3.82 f_r v T}\right] + \frac{DL}{3.82 f_r v T}\left[\frac{C_p}{(k_1+1)} + Gt_s + \frac{Gt_b}{k_2} + \frac{C_c}{k_3} + C_w\right] \quad (1)$$

Milling

$$C = M\left[\frac{D(e+L)}{3.82 Z f_t v} + \frac{2a+e+L}{r} + t_l + \frac{t_o}{N_l} + \frac{Lt_c}{ZT_t}\right] + \frac{L}{ZT_t}\left[\frac{C_p}{(k_1+1)} + Gt_s + \frac{Gt_b}{k_2} + \frac{ZC_c}{k_3} + C_w\right] \quad (2)$$

Drilling and Reaming

$$C = M\left[\frac{D(e+L)}{3.82 f_r v} + \frac{2a+e+L}{r} + t_l + \frac{t_o}{N_l} + \frac{Lt_c}{T_t}\right] + \frac{L}{T_t}\left[\frac{C_p}{(k_1+1)} + Gt_s\right] \quad (3)$$

Tapping

$$C = M\left[\frac{mD(e+L)}{1.91 v} + \frac{2a}{r} + t_l + \frac{t_o}{N_l} + \frac{Lt_c}{T_t}\right] + \frac{L}{T_t}\left[\frac{C_p}{(k_1+1)} + Gt_s\right] \quad (4)$$

$/MIN
FEEDING TIME
RAPID TRAVERSE TIME
LOAD & UNLOAD TIME
SETUP TIME
TOOL CHANGE TIME
TOOL DEPRECIATION COST
TOOL RESHARPENING COST
REBRAZING OR BLADE RESET COST
INSERT OR BLADE COST
GRINDING WHEEL COST

Figure 8-4. Generalized Equations for Cost ($) Per Workpiece for Conventional Machine Tools.

Turning

$$P = \frac{60}{\frac{D(e + L)}{3.82 f_r v} + \frac{2a + e + L}{r} + t_L + \frac{t_o}{N_L} + \frac{D L t_c}{3.82 f_r v T}} \qquad (5)$$

Milling

$$P = \frac{60}{\frac{D(e + L)}{3.82 Z f_t v} + \frac{2a + e + L}{r} + t_L + \frac{t_o}{N_L} + \frac{L t_c}{Z T_t}} \qquad (6)$$

Drilling and Reaming

$$P = \frac{60}{\frac{D(e + L)}{3.82 f_r v} + \frac{2a + e + L}{r} + t_L + \frac{t_o}{N_L} + \frac{L t_c}{T_t}} \qquad (7)$$

Tapping

$$P = \frac{60}{\frac{mD(e + L)}{1.91 v} + \frac{2a}{r} + t_L + \frac{t_o}{N_L} + \frac{L t_c}{T_t}} \qquad (8)$$

Figure 8-5. Generalized Equations for Production Rate (workpieces per hour) for Conventional Machine Tools.

Table 8-6. Derivation of Terms in Cost Equation for Turning and Milling

	TURNING	MILLING
RPM to Cut Speed	$v = \frac{\pi D \times RPM}{12}$; $RPM = \frac{3.82\ v}{D}$	$RPM = \frac{3.82\ v}{D}$
Feed Rate (in./min.)	$\frac{in.}{rev.} \times \frac{rev.}{min.} = f_r \times \frac{3.82\ v}{D}$	$\frac{in.}{tooth} \times no.\ teeth \times \frac{rev.}{min.}$ $f_t \times Z \times \frac{3.82\ v}{D}$
N_s = No. Pcs. Between Sharpenings	$\frac{\text{Tool Life, min.}}{\text{Feed Time, min.}} = \frac{3.82\ f_r\ v\ T}{DL}$	$\frac{\text{Tool Life (Total Length Cut, in.)}}{\text{Length Each Piece, in.}} = \frac{Z\ T_t}{L}$
Feed Time = $\frac{\text{Distance in Feed}}{\text{in./min.}}$	$\frac{L}{\frac{3.82\ f_r\ v}{D}} = \frac{DL}{3.82\ f_r\ v}$	$\frac{(e + L)\ D}{3.82\ Z\ f_t\ v}$
Rapid Traverse Time	$\frac{2a + L}{r}$	$\frac{2a + e + L}{r}$
Setup Time = $\frac{\text{Time to Set Up}}{\text{No. Pcs. in Lot}}$	$\frac{t_o}{N_L}$	$\frac{t_o}{N_L}$
Tool Change Time = $\frac{\text{Time to Change Tool}}{N_s = \text{No. Pcs. Between Sharpenings}}$	$\frac{DL\ t_c}{3.82\ f_r\ v\ T}$	$\frac{L\ t_c}{Z\ T_t}$
Tool Deprec. Cost = $\frac{1}{N_s} \times \frac{\text{Purchased Cost of Cutter}}{\text{No. Times Cutter is Resharpened Before Discarding}}$	$\frac{1}{N_s} \times \frac{C_p}{(k_1 + 1)}$	$\frac{1}{N_s} \times \frac{C_p}{(k_1 + 1)}$
Tool Resharp. Cost = $\frac{1}{N_s} \times G \times$ Time to Resharpen Cutter	$\frac{1}{N_s} \times G\ t_s$	$\frac{1}{N_s} \times G\ t_s$
Rebraze (or blade reset) Cost = $\frac{1}{N_s} \times \frac{\text{Time to Rebraze}}{\text{No. Times Tool is Resharpened Before Blades are Rebrazed}}$	$\frac{1}{N_s} \times G \frac{t_b}{k_2}$	$\frac{1}{N_s} \times G \frac{t_b}{k_2}$
Insert or Blade Cost = $\frac{1}{N_s} \times \frac{\text{Cost of Each Insert or Blade}}{\text{No. Times Blades are Resharpened Before Blades are Discarded}}$	$\frac{1}{N_s} \times \frac{C_c}{k_3}$	$\frac{1}{N_s} \times \frac{Z\ C_c}{k_3}$
Grinding Wheel Cost = $\frac{1}{N_s} \times$ Cost of Grinding Wheel for Resharpening Tool or Cutter	$\frac{1}{N_s} \times C_w$	$\frac{1}{N_s} \times C_w$

Table 8-7. Tool Life Data for Turning

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	TOOL MATERIAL		TOOL GEOMETRY						CUTTING FLUID Code *	DEPTH OF CUT in.	FEED ipr	TOOL LIFE END POINT in.	TOOL LIFE - minutes vs SPEED-feet/minute			
			TRADE NAME	INDUSTRY GRADE	BR°	SR°	SCEA°	ECEA°	RELIEF°	NOSE RADIUS in.								
4340	QUENCHED & TEMPERED TEMPERED MARTENSITE	300	78	C-7	0	6	0	6	6	.040	00	.100	.010	.015	1 15	2 30	3 45	4 60
															470	400	360	325
4340	QUENCHED & TEMPERED TEMPERED MARTENSITE	300	-	T1 HSS	0	15	0	5	5	.005	11 1:20	.060	.010	.060	5 15	6 30	7 45	8 60
															77	63	54	45

*CUTTING FLUID CODE

00 DRY

11 SOLUBLE OIL

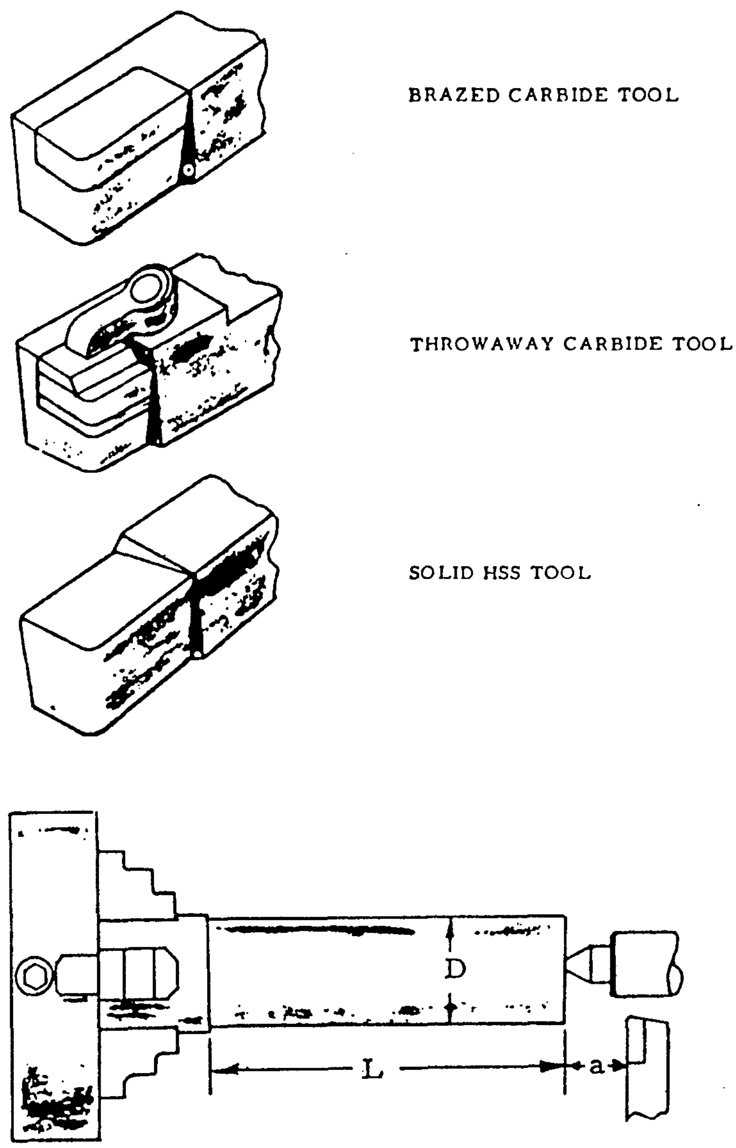


Figure 8-6. Lathe Tools and Setup for Turning Equations.

COST AND PRODUCTION RATE FOR TURNING

BRAZED CARBIDE TOOLS

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	TOOL LIFE MIN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET UP $	TOOL CHNG $	TOOL DEPR $	TOOL SHPN $	RE BRAZ $	TIP COST $	GRIND WHEEL $	TOTAL COST $/PC	PROD RATE PC/HR
1	AISI 4340	300	C-7	470	0.0100	15	1.50	0.11	0.92	0.42	0.49	0.13	1.48	0.16	0.10	0.02	5.33	7.0
2	AISI 4340	300	C-7	400	0.0100	30	1.76	0.11	0.92	0.42	0.29	0.07	0.87	0.10	0.06	0.01	4.61	6.9
3	AISI 4340	300	C-7	360	0.0100	45	1.95	0.11	0.92	0.42	0.21	0.06	0.64	0.07	0.04	0.01	4.44	6.6
4	AISI 4340	300	C-7	325	0.0100	60	2.17	0.11	0.92	0.42	0.18	0.05	0.54	0.06	0.04	0.01	4.48	6.3

COST AND PRODUCTION RATE FOR TURNING

THROWAWAY CARBIDE TOOLS

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	TOOL LIFE MIN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET UP $	INDX INST $	HLDR DEPR $	INSERT COST $	TOTAL COST $/PC	PROD RATE PC/HR
1	AISI 4340	300	C-7	470	0.0100	15	1.50	0.11	0.92	0.42	0.04	0.00	0.10	3.09	8.0
2	AISI 4340	300	C-7	400	0.0100	30	1.76	0.11	0.92	0.42	0.02	0.00	0.06	3.29	7.4
3	AISI 4340	300	C-7	360	0.0100	45	1.95	0.11	0.92	0.42	0.02	0.00	0.04	3.46	7.0
4	AISI 4340	300	C-7	325	0.0100	60	2.17	0.11	0.92	0.42	0.01	0.00	0.04	3.66	6.6

COST AND PRODUCTION RATE FOR TURNING

SOLID HIGH SPEED STEEL TOOLS

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	TOOL LIFE MIN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET UP $	TOOL CHNG $	TOOL DEPR $	TOOL SHPN $	GRIND WHEEL $	TOTAL COST $/PC	PROD RATE PC/HR
5	AISI 4340	300	T-1	77	0.0100	15	9.14	0.11	0.92	0.42	3.01	0.75	6.03	0.03	20.41	1.8
6	AISI 4340	300	T-1	63	0.0100	30	11.17	0.11	0.92	0.42	1.84	0.46	3.68	0.02	18.62	1.7
7	AISI 4340	300	T-1	54	0.0100	45	13.03	0.11	0.92	0.42	1.43	0.35	2.87	0.01	19.15	1.5
8	AISI 4340	300	T-1	45	0.0100	60	15.64	0.11	0.92	0.42	1.29	0.32	2.58	0.01	21.29	1.3

Figure 8-7. Printout of Cost and Production Rate Calculations for Turning Example.

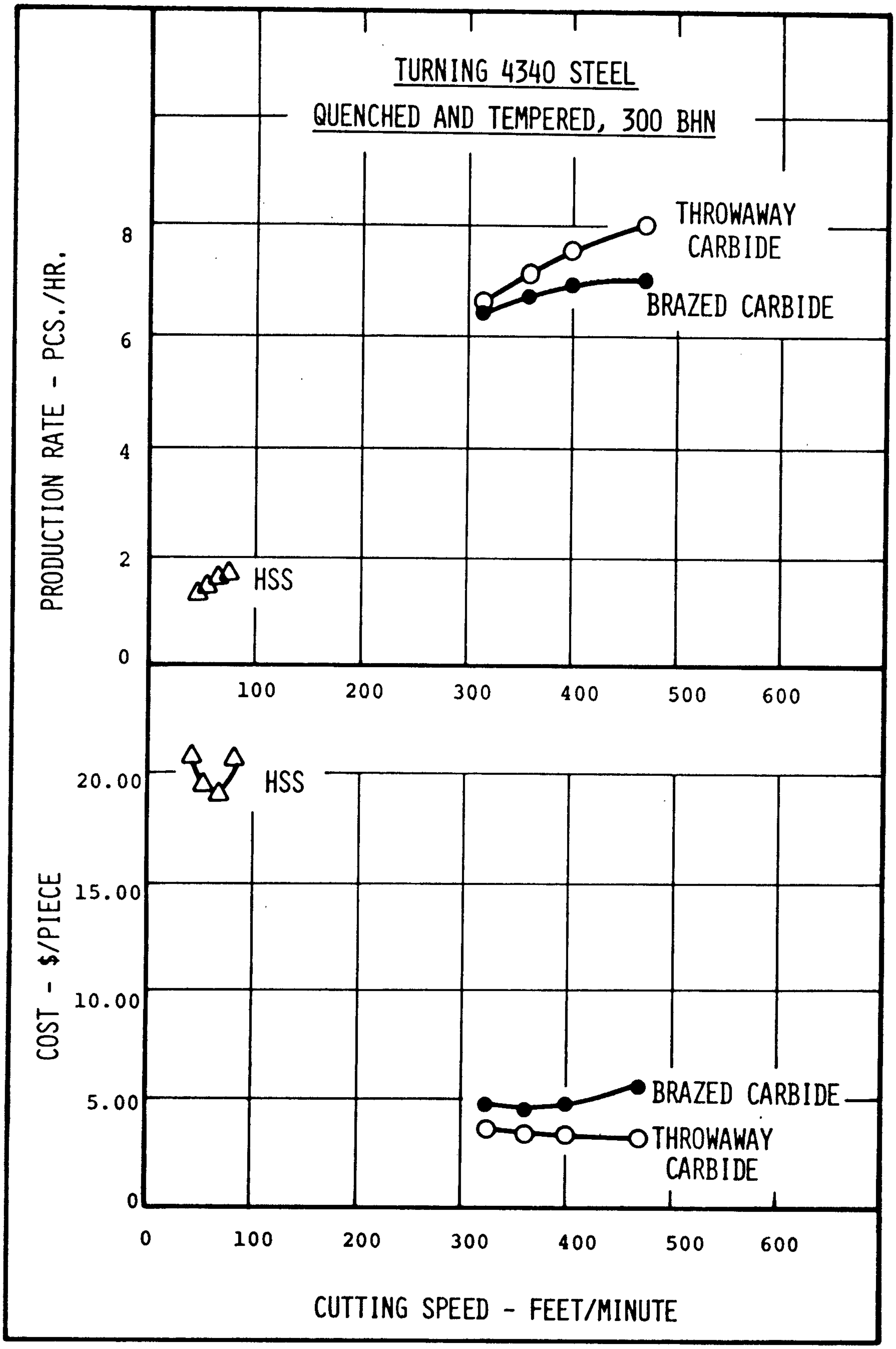


Figure 8-8. Cost and Production Rate Versus Cutting Speed for Turning 4340 Steel, Quenched and Tempered to 300 BHN.

Operation: Turn, shaft, 3.5" diameter by 19" long

Material: 4340 Steel, Q&T, 300 Bhn

References: Table 8-4 Brazed Carbide Tools
Table 8-7 Data Set #1
Figure 8-7 Brazed Carbide Tools, Data Set #1

$$\text{Feed Cost} = M \times \frac{DL}{3.82\, f_r\, v} = \frac{.40 \times 3.5 \times 19}{3.82 \times .010 \times 470} = \$\,1.48$$

$$\text{Rapid Trav. Cost} = M \times \frac{2a + L}{r} = .40 \times \frac{2 \times 4 + 19}{100} = \$\,.11$$

$$\text{Load \& Unload Cost} = M \times t_L = .40 \times 2.3 = \$\,.92$$

$$\text{Setup Cost} = M \times \frac{t_o}{N_L} = .40 \times \frac{21}{20} = \$\,.43$$

$$\text{Tool Change Cost} = M \times \frac{DL\, t_c}{3.82\, f_r\, vT} = \frac{.40 \times 3.5 \times 19 \times 5}{3.82 \times .010 \times 470 \times 15} = \$\,.49$$

$${}^*\text{Tool Depreciation Cost} = \frac{1}{N_s} \times \frac{C_p}{k_1 + 1} = \frac{DL}{3.82\, f_r\, vt} \times \frac{C_p}{k_1 + 1}$$

$$= \frac{3.5 \times 19}{3.82 \times .01 \times 470 \times 15} \times \frac{6.70}{12 + 1} = \frac{1}{4.04} \times \frac{6.70}{13} = \$.13$$

$$\text{Tool Resharpening Cost} = \frac{1}{N_s} \times .40 \times t_s = \frac{1}{4.04} \times .40 \times 15 = \$\,1.48$$

$^*N_s$ = Number of pieces turned before sharpening tool.

Figure 8-9. Calculations for Turning Example.

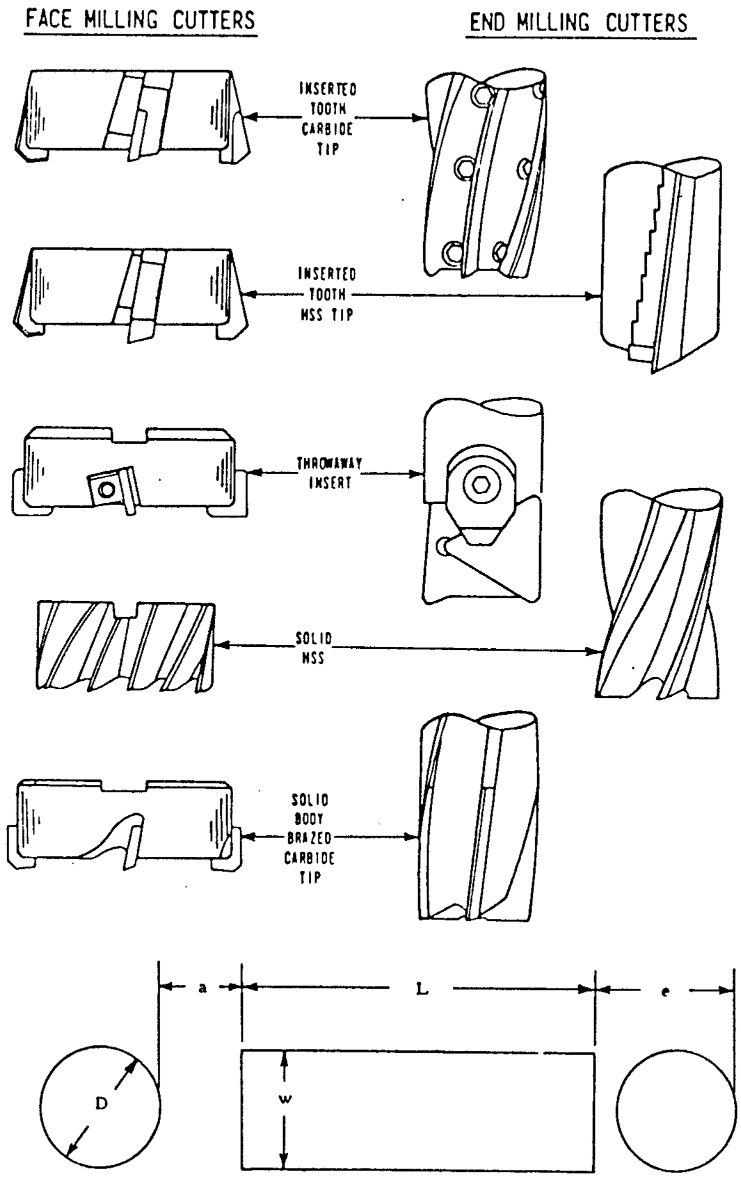


Figure 8-10. Milling Cutters and Setup.

Table 8-8. Example of Data for Face Milling Operation

Operation: Face Mill Block, 2" wide by 8" long Material: 4340 Steel, Q&T, 341 Bhn	Inserted Tooth Carbide Tip	Throwaway Insert	Solid HSS Cutter
a = approach of cutter to work, in.	9.0	9.0	9.0
C_c = cost of each inserted tooth, throwaway insert, or carbide tip, $	2.50	2.35	--
C_p = purchase cost of cutter, $	137.00	248.00	310.00
C_w = cost of grinding wheel for resharpening cutter, $/cutter	.30	--	.35
d = depth of cut, in.	*	*	*
D = diameter of milling cutter, in.	4.0	4.0	4.0
e = overtravel of milling cutter past workpiece, in.	5.0	5.0	5.0
f_t = feed per teeth, in. / tooth	*	*	*
G = labor and overhead cost on cutter grinder, $/min.	.40	--	.40
k_1 = no. of times cutter is resharpened before being discarded	9000	9000	20
k_2 = no. of times cutter is resharpened before inserts (or blades) are reset (or rebrazed)	4	--	--
k_3 = no. of times blades (or inserts) are resharpened (or indexed) before blades (or inserts) are discarded	12	8	--
L = length of workpiece, in.	8.0	8.0	8.0
M = labor and overhead cost on milling machine, $/min.	.40	.40	.40
N = no. of workpieces in lot	100	100	100
r = rapid traverse rate, in. /min.	150	150	150
t_b = time to reset blades or to rebraze cutter teeth, min.	30	--	--
t_c = time to change cutter or index all inserts in cutter, min.	10.0	6.0	10.0
t_L = time to load and unload workpiece, min.	3	3	3
t_o = time to set up milling machine for operation, min.	60	60	60
t_s = time to resharpen cutter, min. /cutter	80	--	80
T_t = tool life measured in inches travel of work to dull one cutter tooth, in.	*	*	*
v = cutting speed, ft. /min.	*	*	*
w = width of cut, in.	2.0	2.0	2.0
Z = no. of teeth in milling cutter	6	6	14

* These values are taken from Tool Life Data, Table 8-9.

Table 8-9. Tool Life Data for Face Milling

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	TOOL MATL. TRADE NAME	TOOL MATL. INDUSTRY GRADE	UP OR DOWN MILLING	TOOL GEOMETRY AR°	RR°	CA°	TR°	INCL°	ECEA°	END REL.° / COR. REL.°	CUTTING FLUID *	DEPTH OF CUT in.	WIDTH OF CUT in.	FEED ipt	TOOL LIFE END POINT in.	TOOL LIFE/TOOTH inches work travel vs SPEED-feet/minute		
4340	QUENCHED & TEMPERED	341	-	T15 HSS	UP	0	0	30	0	0	5	6	11 1:20	.100	2.0	.010	.060	1 17	2 22	3 32
	TEMPERED MARTENSITE											6						93	76	62
4340	QUENCHED & TEMPERED	341	370	C-6	UP	0	-7	45	-5	5	5	6	00	.100	2.0	.005	.016	4 20	5 50	6 80
	TEMPERED MARTENSITE											6						680	550	340

*CUTTING FLUID CODE

00 DRY
11 SOLUBLE OIL

COST AND PRODUCTION RATE FOR MILLING

INSERTED TOOTH - CARBIDE TIP OR HSS BLADE

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED/TOOTH IN	TOOL LIFE IN/TH	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET-UP $	CUTR CHNG $	BODY DEPR $	CUTR SHPN $	BLAD RSET $	BLAD COST $	GRND WHL. $	TOTAL COST $/PC.	PROD RATE PC/HR
4	AISI 4340	341	C-6	680	0.005	20.0	0.27	0.08	1.20	0.24	0.27	0.00	2.13	0.20	0.08	0.02	4.49	11.7
5	AISI 4340	341	C-6	550	0.005	50.0	0.33	0.08	1.20	0.24	0.11	0.00	0.85	0.08	0.03	0.01	2.93	12.2
6	AISI 4340	341	C-6	340	0.005	80.0	0.53	0.08	1.20	0.24	0.07	0.00	0.53	0.05	0.02	0.00	2.73	11.3

COST AND PRODUCTION RATE FOR MILLING

THROWAWAY INSERT

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED/TOOTH IN	TOOL LIFE IN/TH	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET-UP $	INDX INST $	BODY DEPR $	INSERT COST $	TOTAL COST $/PC.	PROD RATE PC/HR
4	AISI 4340	341	C-6	680	0.005	20.0	0.27	0.08	1.20	0.24	0.16	0.00	0.12	2.07	12.3
5	AISI 4340	341	C-6	550	0.005	50.0	0.33	0.08	1.20	0.24	0.06	0.00	0.05	1.96	12.5
6	AISI 4340	341	C-6	340	0.005	80.0	0.53	0.08	1.20	0.24	0.04	0.00	0.03	2.13	11.4

COST AND PRODUCTION RATE FOR MILLING

SOLID HIGH SPEED STEEL CUTTER

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED/TOOTH IN	TOOL LIFE IN/TH	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET-UP $	CUTR CHNG $	CUTR DEPR $	CUTR SHPN $	GRND WHL. $	TOTAL COST $/PC.	PROD RATE PC/HR
1	AISI 4340	341	T15	93	0.010	17.0	0.42	0.08	1.20	0.24	0.13	0.50	1.08	0.01	3.66	11.6
2	AISI 4340	341	T15	76	0.010	22.0	0.51	0.08	1.20	0.24	0.10	0.38	0.83	0.01	3.36	11.2
3	AISI 4340	341	T15	62	0.010	32.0	0.63	0.08	1.20	0.24	0.07	0.26	0.57	0.01	3.06	10.8

Figure 8-11. Printout of Cost and Production Rate Calculations for Face Milling Example.

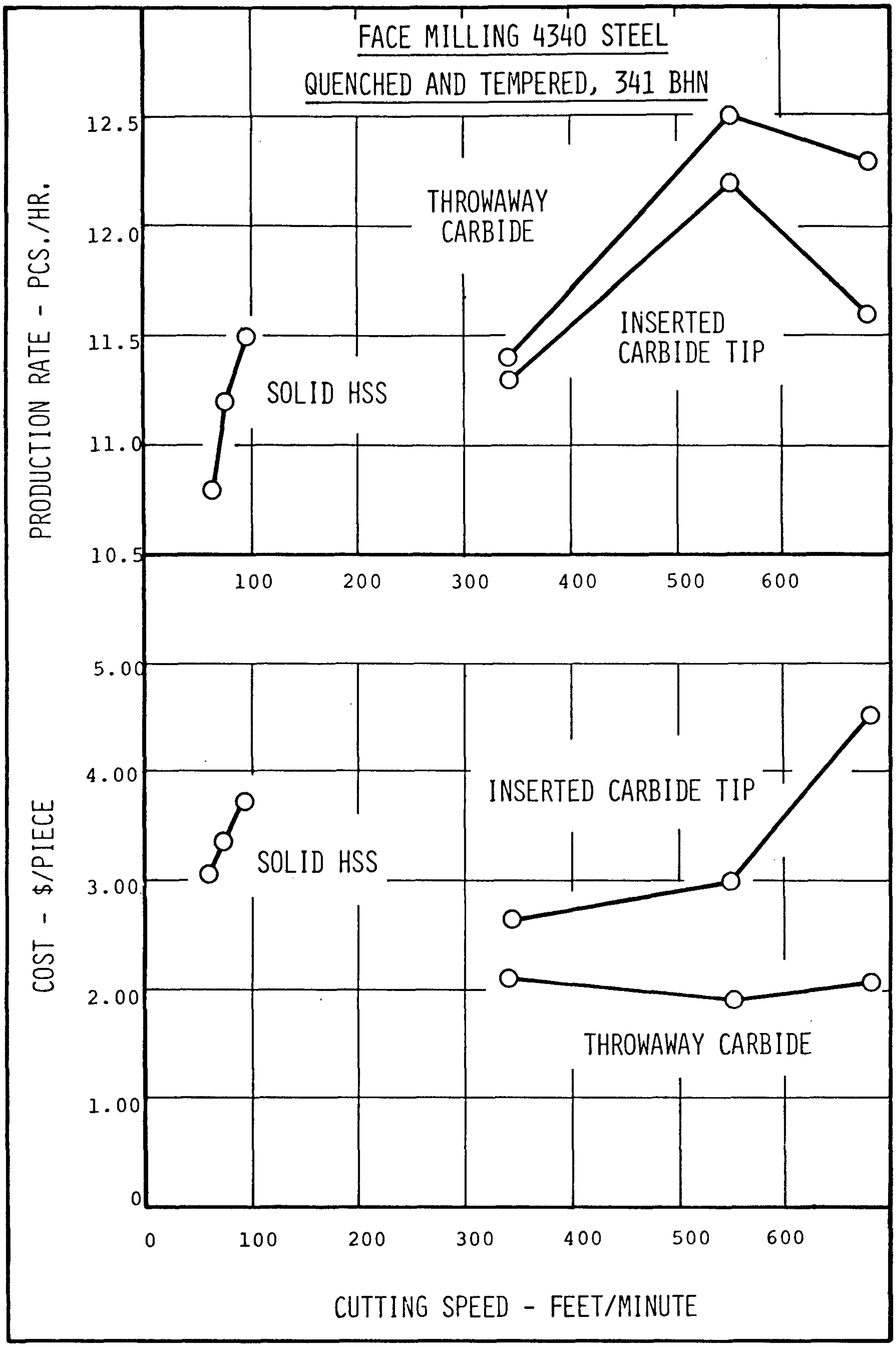
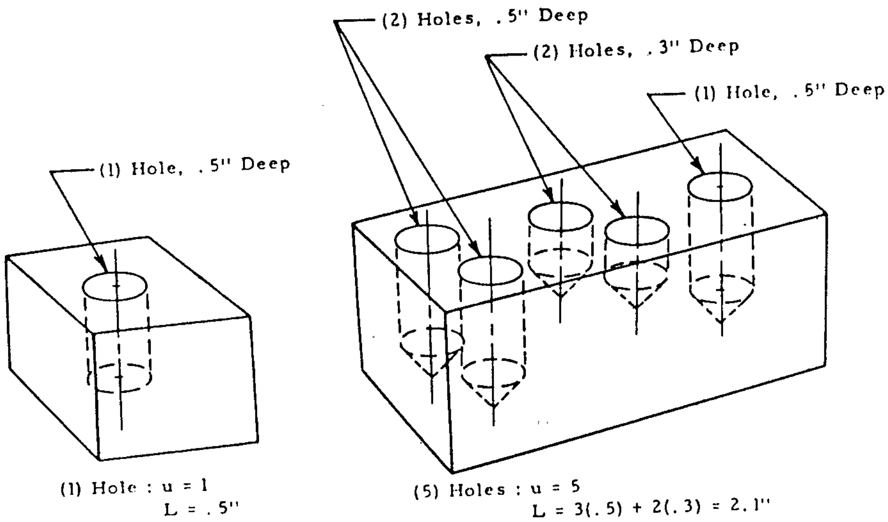


Figure 8-12. Cost and Production Rate Versus Cutting Speed for Face Milling 4340 steel, Quenched and Tempered to 341 BHN.



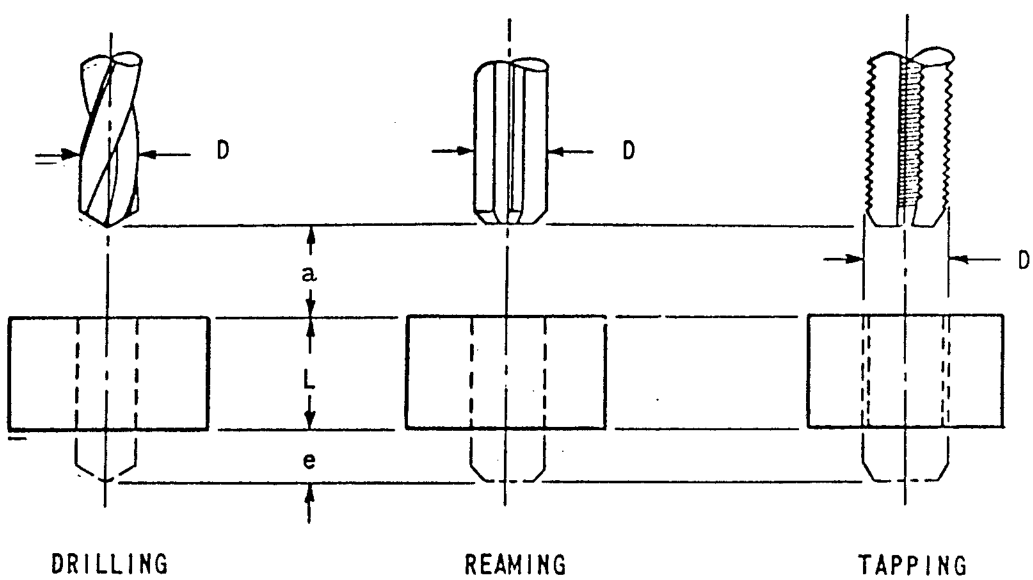


Figure 8-13. Setup for Drilling, Reaming and Tapping.

Table 8-10. Example of Data for Drilling Operation

Operation: Drill (five) .250" diameter holes by .50" long in workpiece

Material: 4340 Steel

a	= approach of drill to work, in.	3.0
C_p	= purchase cost of drill, \$/drill	.92
D	= diameter of drill, in.	.25
f_r	= feed per revolution, in./rev.	*
G	= labor and overhead cost on tool grinder, \$/min.	.40
k_1	= no. of times drill is resharpened before being discarded	12
L	= sum of lengths of all holes of same diameter, in.	2.5
M	= labor and overhead cost on drilling machine, \$/min.	.40
N_L	= no. of workpieces in lot	70
r	= rapid traverse rate, in./min.	100
t_c	= time to change drill, min.	.5
t_L	= time to load and unload workpiece, min.	1.0
t_o	= time to set up drill for operation, min.	25
t_s	= time to resharpen drill, min./drill	5
T_t	= tool life in inches travel of drill to dull drill, in.	**
u	= no. of holes of same diameter in workpiece	5
v	= cutting speed, ft./min.	*
e	= extra travel in drilling, in.	2.5

*These values are taken from Tool Life Data, Table 8-11.

**Drill life data given in Table 8-11 are in number of holes to dull drill, and equation requires these data in inches. Therefore, to obtain T_t, the number of holes is multiplied by the hole length (0.5 in.).

Table 8-11. Tool Life Data for Drilling

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	DRILL MATL. TRADE NAME	DRILL MATL. INDUSTRY GRADE	TYPE DRILL	DRILL SIZE DIA. in.	DRILL SIZE LENGTH in.	DRILL SIZE FLUTE LENGTH in.	DRILL GEOMETRY TYPE POINT	DRILL GEOMETRY HELIX ANGLE°	DRILL GEOMETRY POINT ANGLE°	DRILL GEOMETRY LIP RELIEF°	CUTTING FLUID *	LENGTH OF HOLE in.	FEED ipr	DRILL LIFE END POINT in.	DRILL LIFE NO. OF HOLES vs SPEED-feet/minute			
4340	ANNEALED SPHEROIDIZED CARBIDES + FERRITE	212	-	M1 HSS	TWIST	.250	2.5	1.375	STANDARD	29	118	7	11 1:20	.5 THRU	.002	.015	(1) 30	(2) 50	(3) 100	(4) 220
																	174	158	142	125
"	"	"	-	"	"	"	"	"	"	"	"	"	"	"	.005	"	(5) 10	(6) 100	(7) 200	(8) 280
	"																140	97	82	75

*CUTTING FLUID CODE

11 SOLUBLE OIL

COST AND PRODUCTION RATE FOR DRILLING

DATA SET NO.	WORK MATERIAL	HARDNESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	DRILL LIFE IN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET-UP $	DRLL CHNG $	DRLL DEPR $	DRLL SHPN $	TOTAL COST $/PC	PROD RATE PC/HR
1	AISI 4340	212	M-1	174	0.0020	15.0	0.38	0.04	0.40	0.14	0.03	0.01	0.33	1.34	24.1
2	AISI 4340	212	M-1	158	0.0020	25.0	0.41	0.04	0.40	0.14	0.02	0.01	0.20	1.23	23.5
3	AISI 4340	212	M-1	142	0.0020	50.0	0.46	0.04	0.40	0.14	0.01	0.00	0.10	1.16	22.7
4	AISI 4340	212	M-1	125	0.0020	110.0	0.52	0.04	0.40	0.14	0.00	0.00	0.05	1.16	21.5
5	AISI 4340	212	M-1	140	0.0050	5.0	0.19	0.04	0.40	0.14	0.10	0.04	1.00	1.91	27.5
6	AISI 4340	212	M-1	97	0.0050	50.0	0.27	0.04	0.40	0.14	0.01	0.00	0.10	0.97	27.7
7	AISI 4340	212	M-1	82	0.0050	100.0	0.32	0.04	0.40	0.14	0.00	0.00	0.05	0.96	26.3
8	AISI 4340	212	M-1	75	0.0050	140.0	0.35	0.04	0.40	0.14	0.00	0.00	0.04	0.98	25.5

Figure 8-14. Printout of Cost and Production Rate Calculations for Drilling Example.

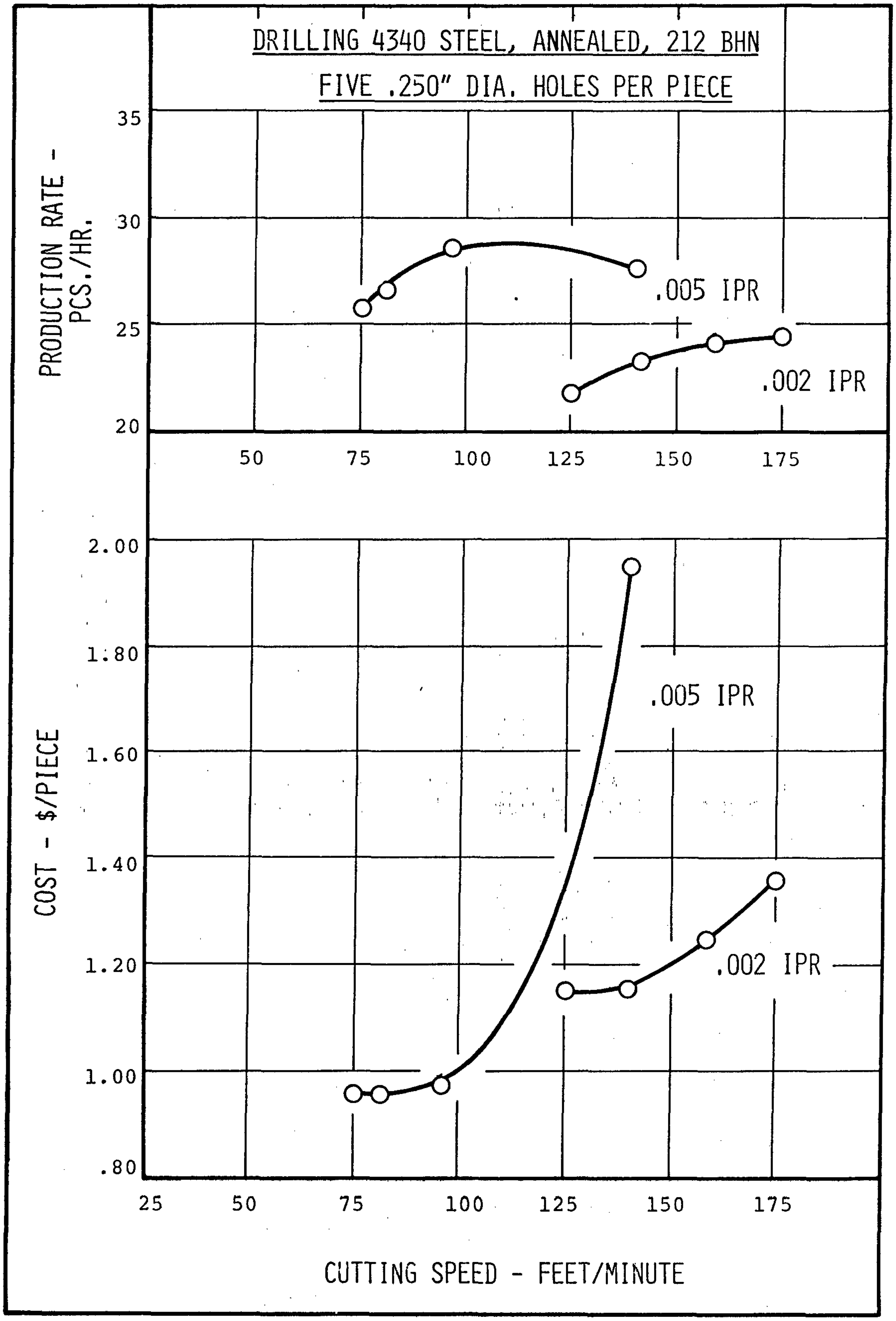


Figure 8-15. Cost and Production Rate Versus Cutting Speed for Drilling 4340 Steel, Annealed to 212 BHN.

TURNING INSERTS — COST & PRODUCTION
MACHINABILITY DATA CENTER PROGRAM

STEP	HP-67/97		KEYS		OUTPUT
1	Load Strip				
2	Initialize		RTN	R/S	3.00†
3	Load-Unload Time Index Time Rapid Trav Dist Rapid Trav Rate	min min in in/min	ENTER ENTER ENTER R/S		4.00†
4	Insert Cost # Cutting Edges Set-up Time # Pieces in Lot	S min 	ENTER ENTER ENTER R/S		5.00†
5	Preset Cost Overhead Dull Tool Rep Time	S S/min min	ENTER ENTER R/S		6.00†
6	Diam Work Extra Travel Length of Cut	in in in	ENTER ENTER R/S		7.00†
7	Tool Life Speed Feed	min fpm ipr	ENTER ENTER R/S		PTS/TL§
8	for Times or for Costs		CF SF	1 1	
9	Constant (cost or time) Feeding (cost or time) Tool (cost or time) Total (cost or time)		A B C D		SorMin Sor Min SorMin SorMin
*	for New Tool Life, V&F		E		7.00†
*	for New Geometry	GTO	6	R/S	6.00†

†These prompting outputs give the numbers of the next step to be executed.

§This is the output of the number of parts that can be machined with one edge of one insert.

1 *Select the proper magnetic strip and insert it into the calculator.*

2 *Initialize*

3 *Enter data and press appropriate keys*

2.3 0 27.2 100.
3.15 8. 21. 20.
0 .40 .4
3.5 .2 19.
60. 325. .01

11.2 Parts per edge

4 *Execute steps 8 and 9 for output*

Cost (S)	Prod. Time (min.)
1.45	3.62
2.17	5.41
.05	.04
3.67	9.07

5 *Loop back using * steps if desired*

Figure 8-16. Instructions and Sample Inputs and Outputs for Cost and Production Calculations Using the HP-67 Calculator.

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